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INDIA	6
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JAPAN	66
MANCHURIA & KOREA	10
NEW ZEALAND	2
POLAND	1
SOUTH AFRICA	49
SOUTH AMERICA	10
SPAIN	2
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U.S.A.	582
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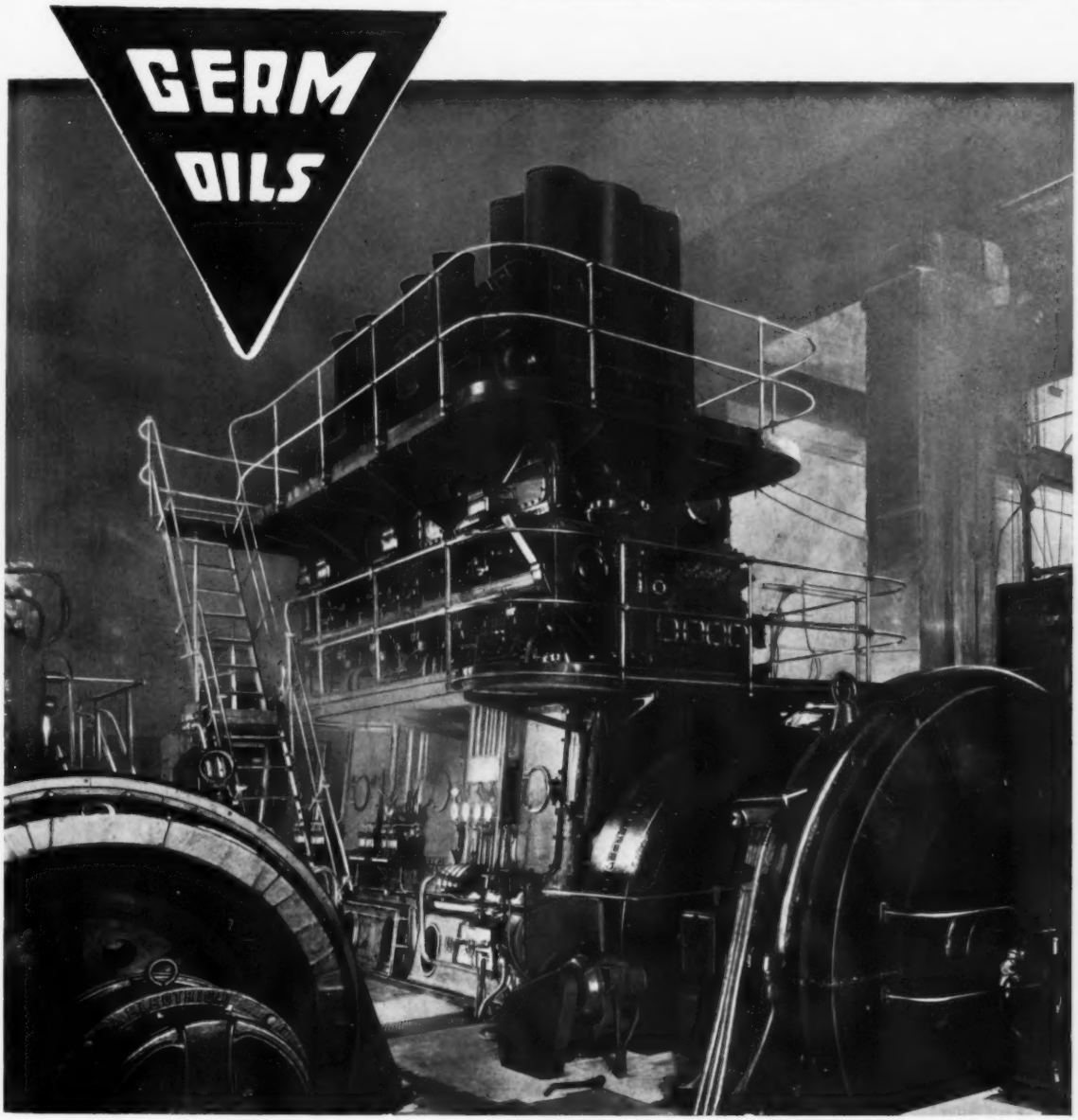

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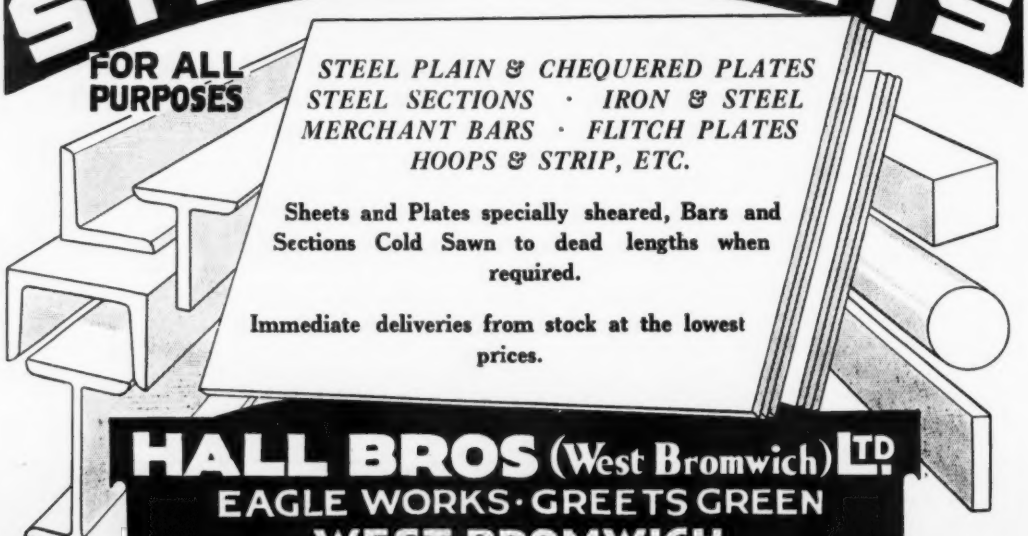

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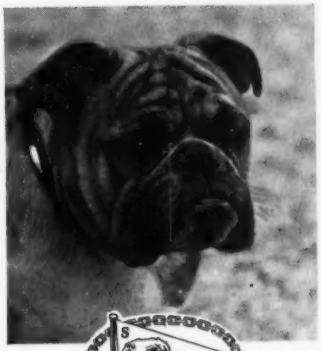

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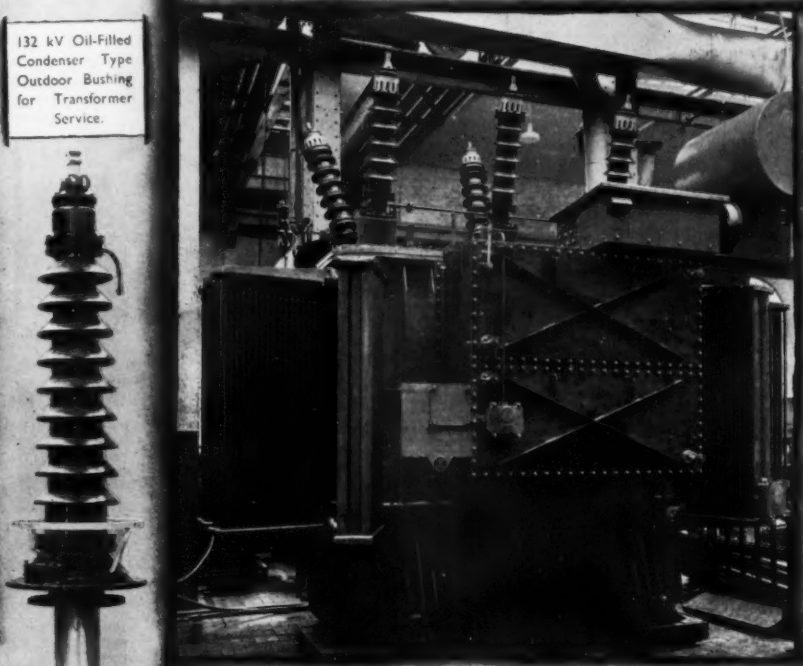

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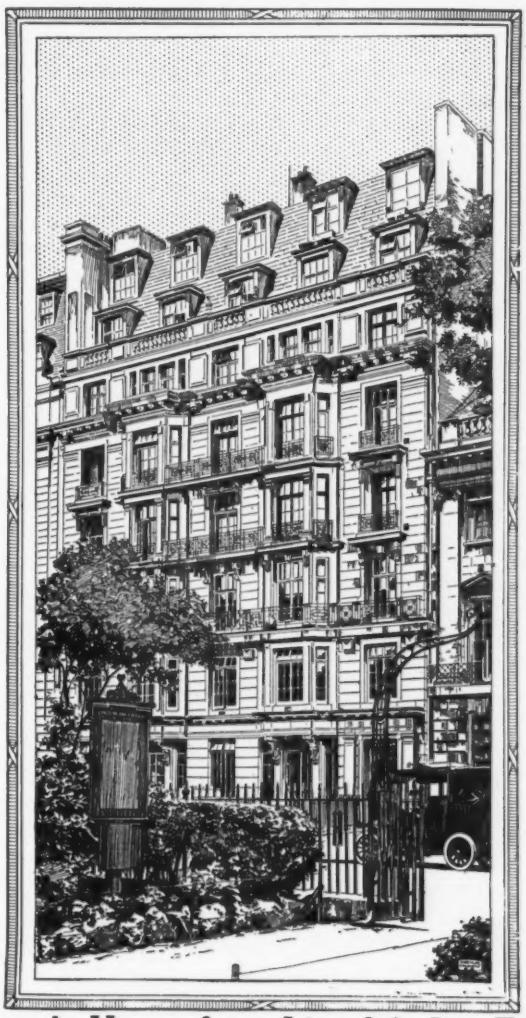

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Glenlee Power Station, from head of Pipeline.

The English Electric Journal

Vol. VIII. No. 3 SEPTEMBER, 1936 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

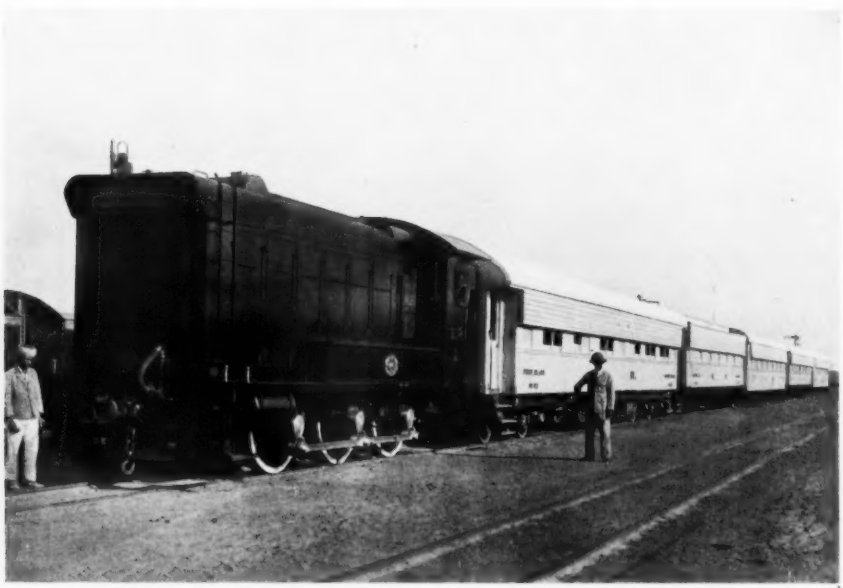
The series of articles by Mr. H. L. Bazalgette describing the first stage of the Galloway Water Power Company's hydro-electric scheme is concluded in the first article of this issue. The final instalment describes and illustrates the turbines and alternators at the Glenlee Power Station. As the head of water at this station is higher than that obtaining at Tongland, the turbines at Glenlee though of smaller dimensions are of slightly greater output, and due to the different hydraulic conditions they form an interesting contrast to the turbines at Tongland. The article concludes with a description of the switchgear and control gear at the Tongland and Glenlee stations, the whole of which was supplied and installed by the Company.

It is proposed to describe in a future number of this Journal the second stage of the Galloway Water Power Company's hydro-electric scheme comprising the Kendoon, Earlstoun and Carsfad stations.

Multi-cylinder steam turbines have been developed as a result of modern

power requirements necessitating large and efficient generating units operating at high initial steam pressures and temperatures. In the second article Mr. J. T. Moore describes the Company's multi-cylinder impulse-reaction turbines and explains the considerations which have led the Company to adopt the pure impulse type for the high-pressure cylinder and the reaction type for the low-pressure cylinder. That this policy has been justified is shown by the high-efficiency and reliability in service of turbines of this design manufactured by the Company. It is interesting to note that the Company were constructing multi-cylinder turbines as early as 1923. The article is illustrated by examples of multi-cylinder turbo-alternator sets in service in the power stations of various electricity supply undertakings.

"Scientific Developments in Transformer Construction," by R. M. Charley is the title of the concluding article. In this the author outlines the progress which has taken place in transformer design during recent years and refers to several interesting and special problems of design and their solution. Further articles in subsequent issues of the Journal will describe several outstanding transformers of recent construction, and some new special applications of transformers.



350 H.P. "English Electric"-Hawthorn, Leslie Diesel-Electric Locomotive in operation on the Sudan Government Railways' system; a second similar locomotive will shortly be put in service.

The Galloway Water Power Scheme.

By H. L. BAZAGETTE, A.C.G.I., A.M.I.C.E.

(*Concluded from Page 46, Vol. VIII, No. 2.*)

Glenlee Power Station.

Glenlee Power Station lies some 17 miles to the North of Tongland and discharges into the River Ken through a tailrace 900 yards long. The other four power stations in the Galloway Scheme are located in series on the Rivers Ken and Dee, but Glenlee is supplied from an artificial Loch, Clatteringshaws, which is situated on the upper reaches of the Blackwater of Dee on the site of one of the early victories of Robert the Bruce. The water is carried by a tunnel, 19,000 ft. long, and a pipeline to Glenlee Power Station, and the *Frontispiece* to this issue shows a view of the station, taken from the portal at the end of the tunnel and from the head of the pipeline. The latter is 1,700 ft. long, and consists of a single pipe decreasing in diameter from 9 ft. 6 in. at the top to 8 ft. 4 in. at a point near the Power Station, where it bifurcates into two 6 ft. diameter pipes, which supply the two turbines. The Power Station is a simple steel-framed structure with reinforced concrete walls, and comprises a main turbine room, a three-storey annexe, in which is housed the switchgear, office and living accommodation.

The layout of the turbine room is similar in its main features to that of Tongland, being of the same single-floor accessible design with the generators supported on concrete pedestals, and the governor and auxiliary apparatus located on the main floor.

Hydraulic Equipment.

The Power Station contains two main vertical shaft reaction turbines and two horizontal shaft reaction turbines. Each of the main turbines gives a maximum continuous output of 18,000 h.p. under a nett head of 380 ft., and each of the auxiliary turbines an output of 750 h.p. under the same head. The main turbines run at 428 r.p.m., and the auxiliary turbines at 1,000 r.p.m. A study of the cross section in Fig. 22 will show that the construction of the main Glenlee turbines forms in some respects an interesting contrast to that of the Tongland turbines.

In consequence of the higher head, they are of rather smaller dimensions though slightly greater in output, and the spiral casings consist of steel castings instead of being fabricated from mild steel plate.

Main valves of the Company's patent streamline cylindrical balanced type are provided, and also relief valves which form prolongations of the pipelines.

The runners, instead of being cast steel, consist of high-tensile propeller bronze.

All these features, which are directly due to differing hydraulic conditions, are worthy of individual study.

The main inlet valves are specially designed as a protective feature for the security of the plant.

The cylindrical piston which forms the closing member of the valve, is designed as a hollow cylinder, so arranged that the radial and axial forces are completely balanced in all positions. Since the area of the piston head is small, the axial thrust on it, due to changes of pressure brought about by variations of flow during opening or closing, is also small, and the rapid drop in pressure, which always occurs on the downstream side of a valve just before complete closure (causing slam shutting in many valves), has no effect on the piston, which cannot " slam " shut. The rate of travel of the valve is determined under all conditions by a travelling control screw, the pressure water having to pass round an increasing number of threads before reaching the servomotor ; this has the effect of increasing the path to be traversed, slows up the valve piston, and causes the last part of the stroke to be carried out very slowly. Since the piston moves much more rapidly during the earlier part of the closing-stroke the total operating period is

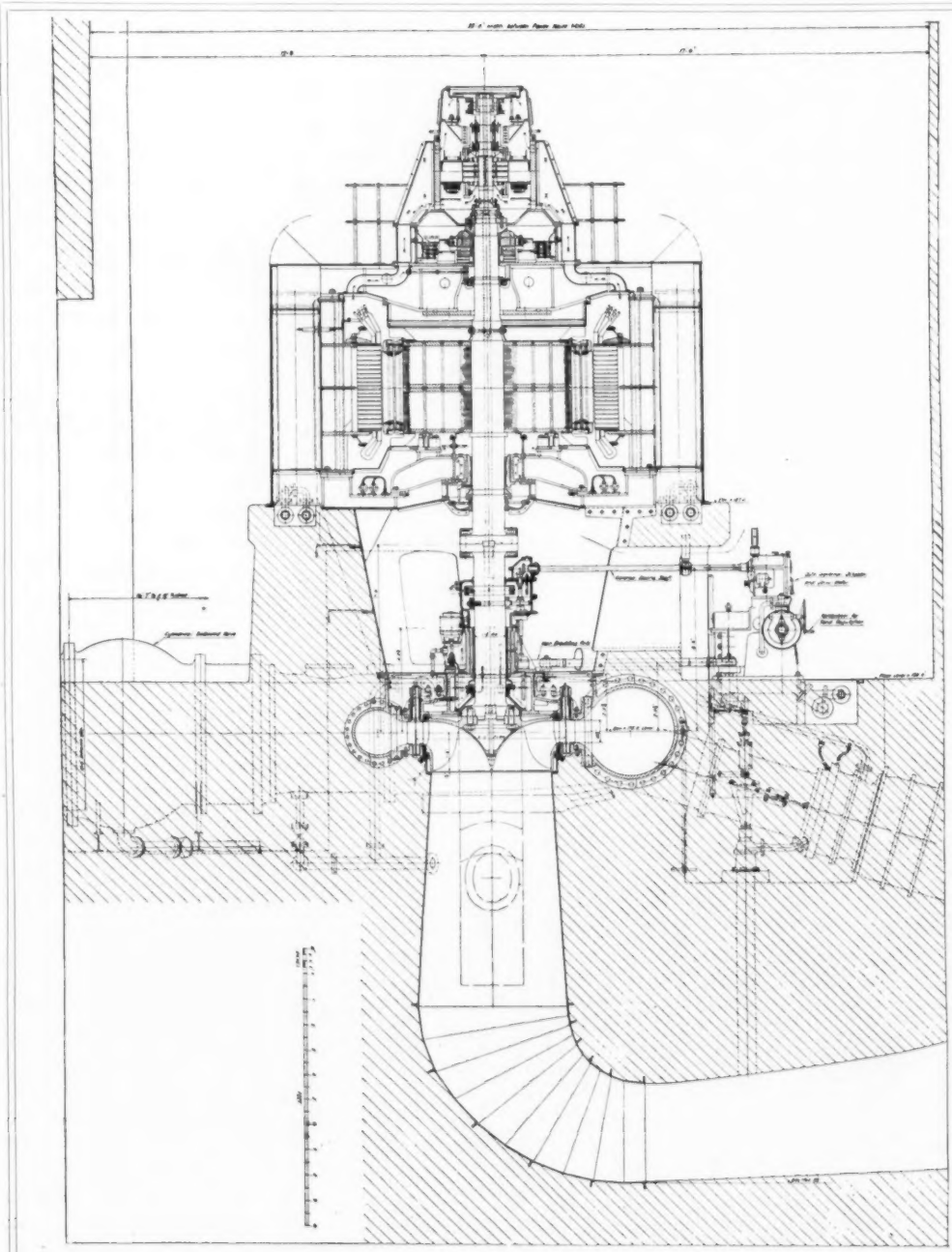


Fig. 22.—Sectional elevation through one of the Glenlee Water Turbines and Generators.

small, while, at the same time, " slam " shutting and opening is entirely eliminated.

The main valves at Glenlee are 6 ft. inlet diameter and 4 ft. 6 in. outlet diameter ; Fig. 23 shows one being lowered into position on the site. The valves are located inside the Power Station and are accessible to the main crane, which represents a further advantage of the single-floor power station design.

The relief valves are also of the cylindrical balanced type and are constructed largely on the same principle as the main inlet valves. They are fitted to branches on the spiral casings and are so located that they prolong the pipeline and the water is thus conveyed by the quickest and most direct route to the tailrace. These valves open in synchronism with the closing of the turbine gates, and the water being discharged in the form of a hollow cone, quickly loses its velocity in air friction and reaches the tailrace as a fine spray ; there is, therefore, no need for a baffle or armouring to protect the tailrace. The valve consists primarily of a main body of cast steel with stainless steel servomotor cylinder, a piston of stainless steel, and an inner body of cast steel with stainless steel coating on the barrel and ribs upon which the piston slides.

By means of the relief valves excessive pressure hammer in the pipeline due to load fluctuations is entirely avoided.

The turbine spiral casing consists of a casting of high-quality steel stiffened by stay bolts of special high-tensile steel, which bridge the throat gap between the two inner flanges ; the inlet diameter of the casing is 4 ft. 6 in. It is provided with a relief valve branch and, as in the case of the Tongland casing, it is embedded in concrete. Surmounting the casing is the fabricated generator supporting barrel, which transmits the generator weight to the foundations. Fig. 24 shows one of the spiral casing and generator support assemblies at Rugby Works.

The draught tubes, through which the water from the turbines is discharged, are formed in the concrete round liners consisting of mild steel plates fabricated by electro-welding. They consist of curved and straight sections, which are carefully shaped, stiffened by ribs, and anchored to the concrete by steel hooks. The separate sections were sent to the site and there welded together into a complete shell. Fig. 25 shows one of the draught tubes assembled at Rugby.

The main turbine runners are castings of special high-tensile propeller bronze, which has been

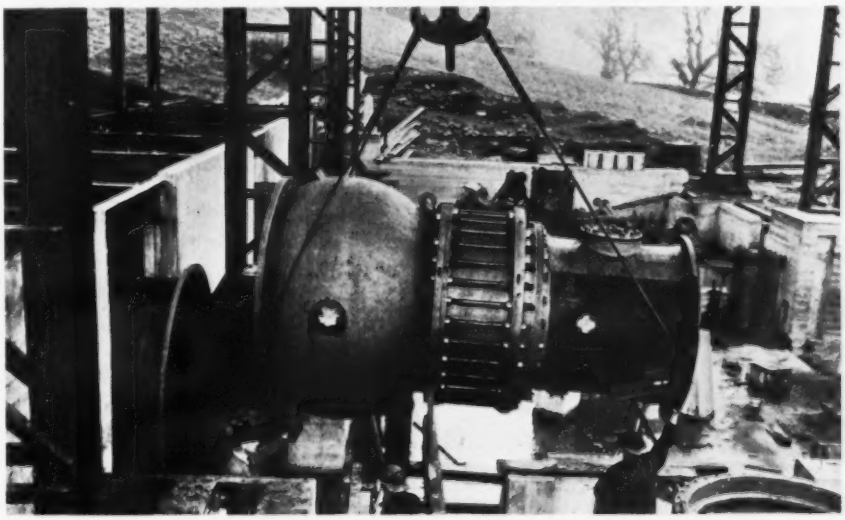


Fig. 23.—Cylindrical Balanced Main Valve for Glenlee being lowered into position.

specially evolved to withstand erosion and is extensively used by the Admiralty for ships' propellers. It stands up remarkably well against exacting conditions of suction resulting from varying heads and has been used by this Company for several large plants.

The runner disc and rim are protected by shrunk-on high-tensile steel rings ; the inlet and outlet edges of the wheel are streamlined, the whole inside of the runner being polished to render it smooth and free from any casting irregularities.

The runner is connected to the shaft by a rigid flange and the whole torque is transmitted by two laid-in transversal keys with interference fit, the fixing studs working under tensile stress only. As the studs are locked in the shaft-flange and have clearance in the disc holes, no reamering or adjusting is necessary in the field when changing the runner.

The turbine governors are of the Company's automatic oil pressure type, and are similar to those installed at Tongland, which were described in the second article (Vol. viii, No. 2).

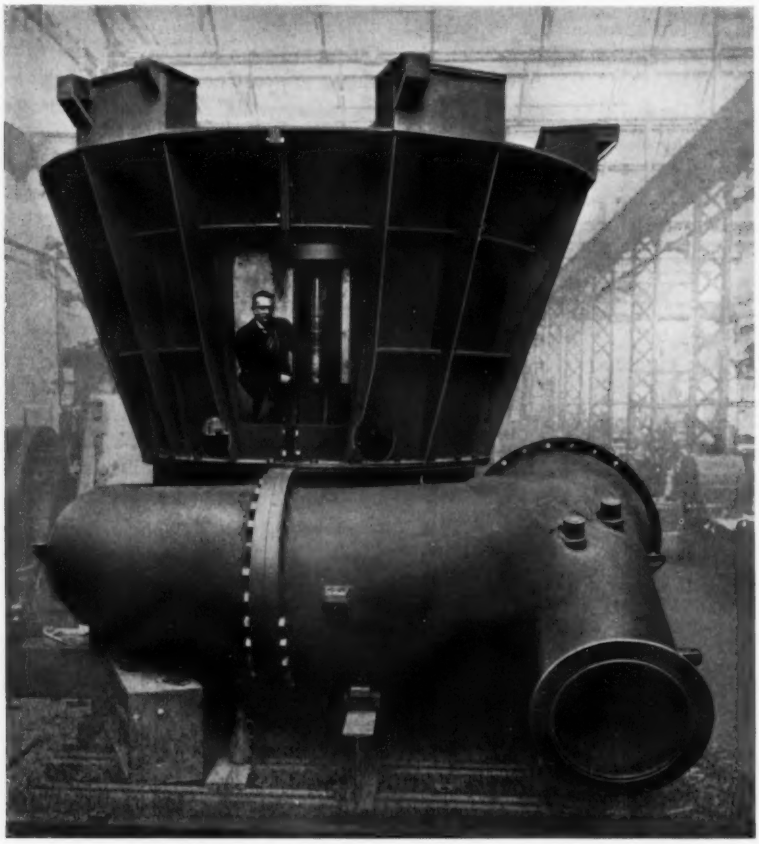


Fig. 24.—Glenlee Spiral Casing and Generator support assembly at Rugby Works.

The regulating mechanism and auxiliary apparatus are also on the same lines as the Tongland design, and need not again be dealt with in detail.

The 750 h.p. auxiliary turbines are of the horizontal reaction type and the runners, of special bronze, are overhung on the generator shafts, the turbines having no separate bearings of their own. This overhung arrangement is found to be

very compact and is now generally the Company's standard practice for horizontal units, as the joint design and manufacture of the hydraulic and electrical portions ensures a satisfactory working combination.

GENERATORS.

Each of the two main alternators is designed for a maximum continuous rating of 15,000 kVA., 0.8 P.F., 3-phase, 50 cycles, 11,000 volts at 428 r.p.m., with temperature rises not exceeding those specified in B.S.S. 226/1925. Each machine is also capable of supplying, for line charging purposes, 50 per cent. of its rated kVA. at zero leading power factor, with positive excitation at the sliprings.

To meet the requirements of the turbine the alternator rotor embodies a flywheel effect of 0.72×10^6 lbs./ft.^{2} (WR^2), and is designed for a runaway speed 90 per cent. above normal, with a factor of safety of not less than 3.5 based on the ultimate strength of the materials. The maximum hydraulic thrust on the turbine runner amounts to 17.5 tons, which, when added to the weight of the revolving parts, imposes a total downward load of 66 tons on the alternator thrust bearing.

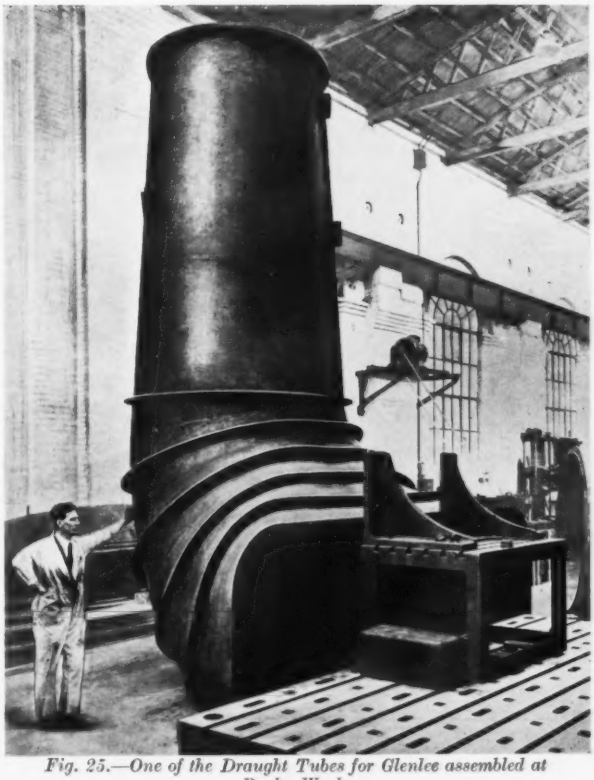


Fig. 25.—One of the Draught Tubes for Glenlee assembled at Rugby Works.

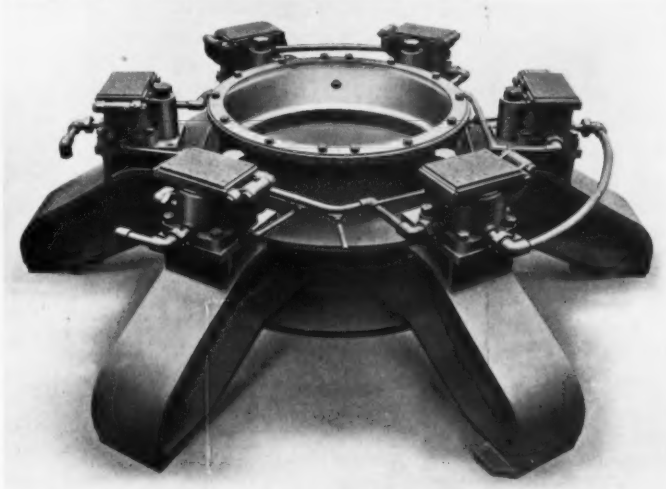


Fig. 26.—Bracket for Lower Guide Bearing.

While the umbrella type of vertical shaft generator as employed at Tongland Power Station, is superior for applications requiring slow speed large diameter machines, the hydraulic conditions at Glenlee are such as to necessitate the use of relatively high speed (428 r.p.m.), and, consequently, small diameter generators. The umbrella type does not lend itself to these latter conditions because the single-guide bearing cannot be placed close enough to the plane of the centre of gravity of the rotor.

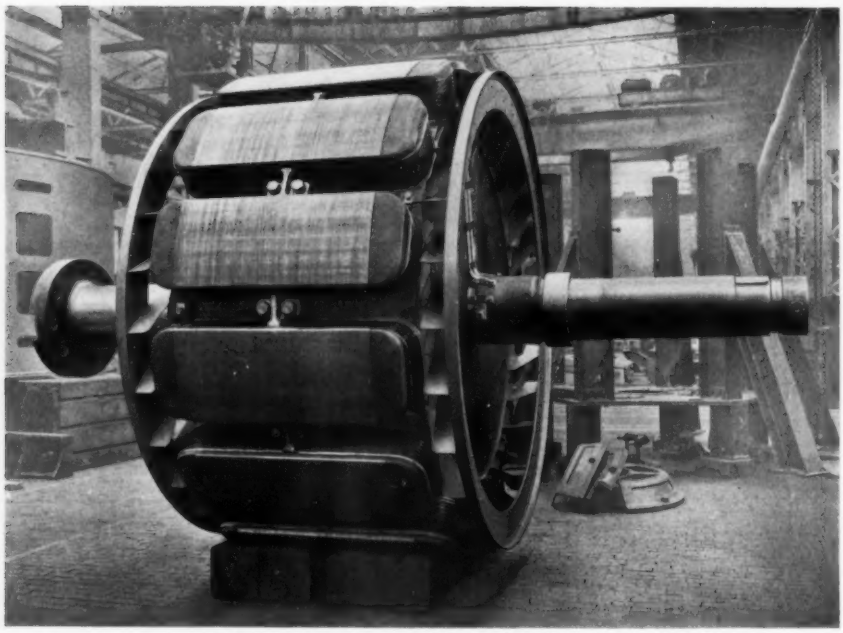


Fig. 27.—Rotor for one of the Glenlee Alternators.

For these reasons the vertical shaft generators at Glenlee Power Station, as will be seen from Fig. 22, are of the conventional two-guide bearing type, the thrust and upper guide bearing being housed in one oil pot mounted on the upper bracket. The thrust bearing load is thus transmitted via the upper bracket through the stator frame to the foundations.

The stationary members of both the thrust and upper guide bearing consist of tilting pads on the Michell principle. Since water-cooled coils are immersed in the oil, external circulation is not required. The cover of the thrust bearing casing provides a seating for the exciter magnet and slipring brush holders.

The lower bracket, which is shown in Fig. 26, serves as a housing for the sleeve-type lower guide bearing and, at the same time, as a support for the brake cylinders. Oil circulation for this bearing is provided by the pump supplying the turbine guide. The bearing can be removed downwards for inspection without disturbing any other part of the unit. The brakes can be seen in the photograph.

The rotor hub, which is built up from boiler plate, is in two sections, the plates in each packet being clamped between thick endplates. The underside of the rotor hub is polished to provide a braking surface, the brakes being capable of bringing the rotor to rest from full speed in about 5 minutes when supplied with compressed air at 40/50 lbs. per sq. in. When inspecting the thrust bearing, the weight of the revolving parts can be supported by applying oil at a pressure of 1,000 lbs. per sq. in. to the six brake-cylinders, and then, if desired, by using the follow-up jack screws, one of which is provided alongside each brake-cylinder.

The solid rotor body formed from the steel plates was machined all over and dovetails cut in the outer periphery to receive the poles. The body was then shrunk on to the shaft. One of the completed rotors is shown in Fig. 27.

The alternators are self-ventilated by means of fans on the rotor and similarly to the Tongland machines, operate on the closed-circuit principle, the hot air being passed through six water-cooled air-coolers before re-entering the fans. The

exciters are also totally-enclosed and forced-ventilated.

The auxiliary generators are rated at 500 kW., 400 volts, 50 cycles, 1,000 r.p.m., with an overload capacity of 20 per cent. for two hours.

The stator frames are of fabricated steel construction, and the rotor bodies are hexagonal in shape and forged in one piece with the shaft.

The auxiliary units are located at one end of the main turbine room and are fed by a branch pipe from one of the main pipelines. Valves are provided so that the units may be run either separately or both together; they discharge into the same tailrace as the main turbines.

Fig. 28 shows the interior of Glenlee Power Station. It will be noted that the concrete pedestals upon which the generators stand are circular in form and are not integral with the upstream wall of the Power Station building, as in the case of Tongland. The units have also a higher and more towering appearance due to the fundamental difference in generator design already described.

It will be noticed that the arrangement of such auxiliaries as the governors, oil pumping sets and pressure receivers, filters, gauge boards, etc., is the same as that adopted at Tongland, all these items being grouped conveniently on the station floor at the foot of the generator pedestals. This arrangement is adopted at all five Power Stations comprising the Galloway scheme, as it is realised that such uniformity contributes to operating efficiency.

Switchgear at the Tongland and Glenlee Power Stations.

The whole of the switch and control gear in the Tongland and Glenlee Power Stations was manufactured and installed by The English Electric

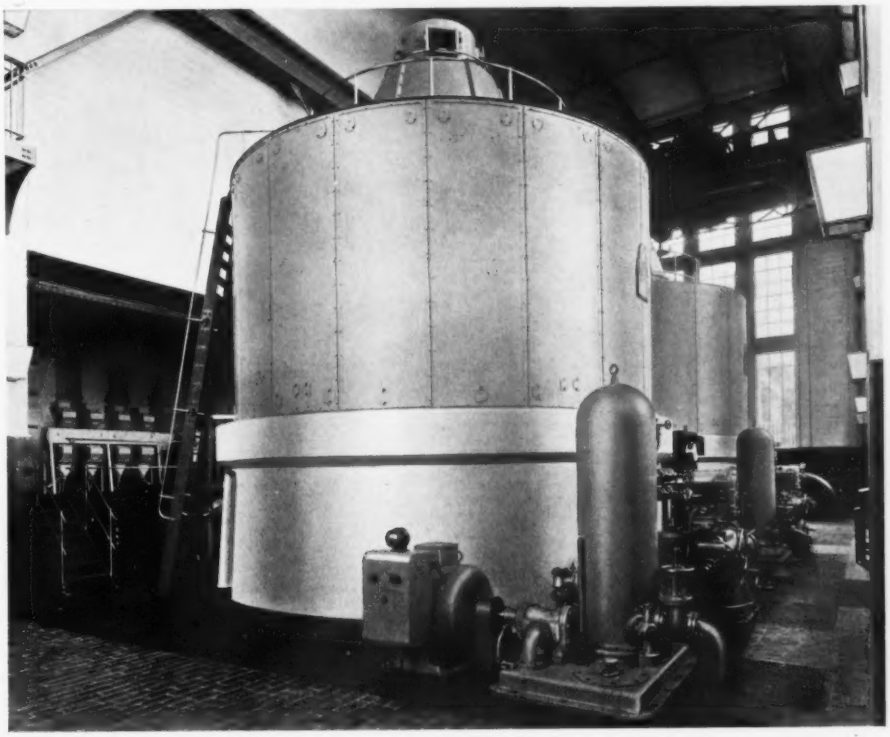


Fig. 28.—Interior of the Glenlee Power Station, showing the two 12,000 kW. Water turbine-driven Alternators.

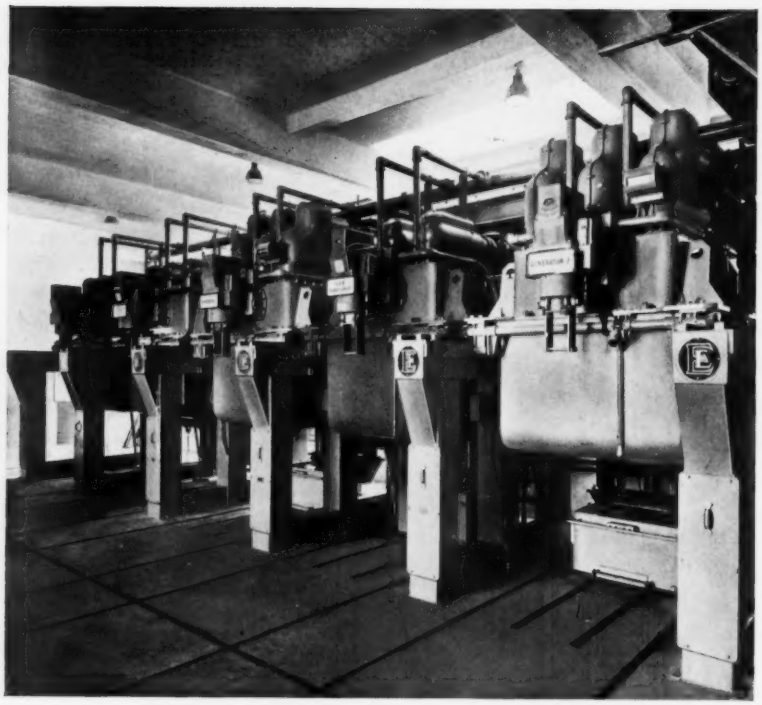


Fig. 29.—11,000 volt, 750,000 kVA. rupturing capacity main metalclad switchgear at Tongland Power Station.

Company, who were also responsible as Main Contractors for the batteries, main and multicore cables, and the complete lighting and heating installations. The layouts of the control and switchrooms, diagrams, cable runs and schedules were prepared in every detail and the whole installation was carried out by this Company and its sub-contractors.

Plate I shows the main system diagram for the Galloway scheme with the interconnections to the Central Electricity Board's system.

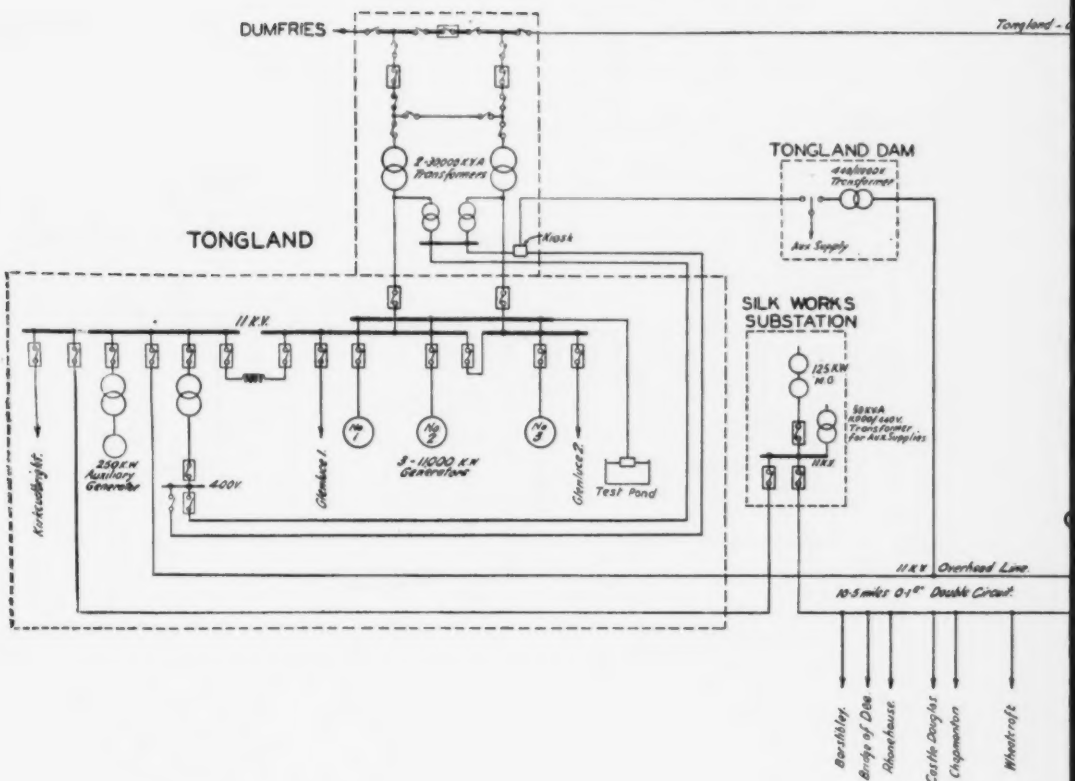
The switchgear equipment is very similar at both Power Stations and comprises a main 11,000 volt switchboard, a local supply 11,000 volt switchboard, a 400 volt switch and fuse-switchboard for station auxiliaries, and a similar 110 volt board for lighting and heating. All the foregoing are of metalclad construction. A switchboard of the usual type is provided for the 110 volt station battery with its charging equipment.

A miniature type control board controls the 11,000 volt switchgear. Separate cubicle boards are provided for the protective relays, integrating meters and automatic voltage regulators.

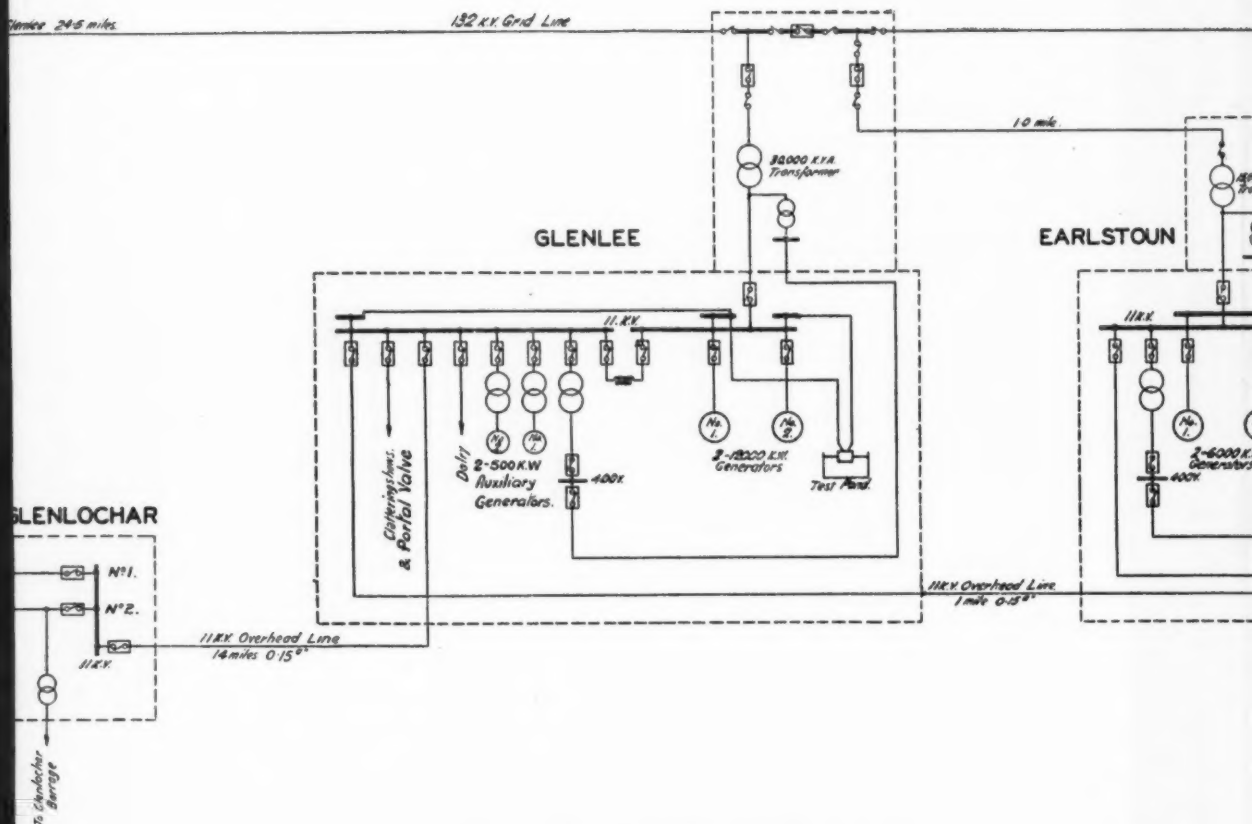
The main generators and C.E.B. feeders are controlled by the main metalclad 750,000 kVA. rupturing capacity switchboard. This consists of "English Electric" type O.L.G. 2A. units, which are shown in Fig. 29. The construction follows the well-known principles of horizontal draw-out metalclad switchgear, and represents the most up-to-date practice in this type of apparatus. Fabrication takes a prominent part in the construction, the main frames, switch top-plates and tanks, busbar and current transformer chambers being manufactured in this way. The phases are separated by earthed metal throughout, and automatic protective shutters and a full set of interlocks are provided. The instrument transformers are accessible from the front of the board, and such access is simple and convenient.

The circuit-breakers are solenoid operated and have their mechanisms enclosed in such a way that the speed of opening is unaffected by pressure inside the tank. All circuit-breakers of similar type are interchangeable.

An electrically-operated lifting and transporting truck is used for removing circuit-breakers from their supporting frames, or tanks from circuit-breakers. A pair of "hospital" frames is provided at the end of the board, to which any circuit-breaker may be removed for inspection or repair.


DUMFRIES
Tongland -
2-3000 KVA Transformers
TONGLAND DAM
4400/600V Transformer
Aux Supply
TONGLAND
Kiosk
11 KV.
SILK WORKS SUBSTATION
125 KW M.G.
50 KVA 4000/440V. Transformer for Aux. Supplies
11KV
Kirkcudbright
250 KW Auxiliary Generator
400V
Glenlee 1
No 1
No 2
No 3
3 - 11000 KW Generators
Glenlee 2
Test Pond
11 KV Overhead Line
10·5 miles 0·1" Double Circuit
Borthwick
Bridge of Dee
Rhonehouse
Castle Douglas
Chapelknowe
Wheatroft

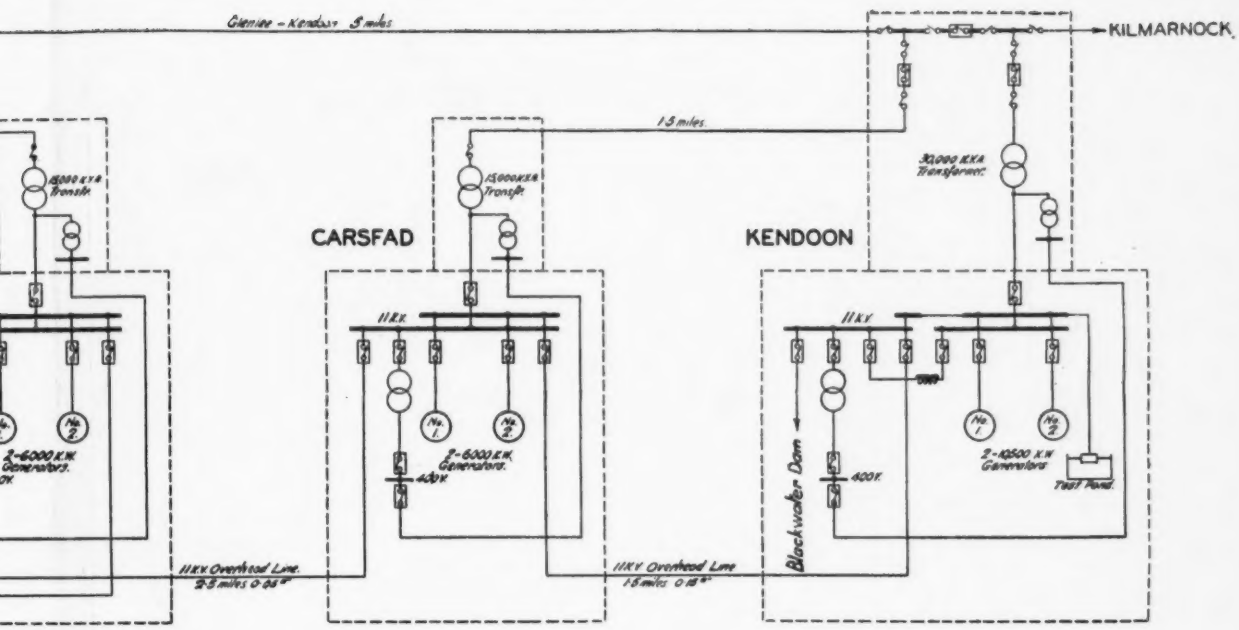
SHOWIN



SYSTEM DIAGRAM

NG THE MAIN CONNECTIONS OF THE GALLOWAY WATER POWER COMP

AND INTERCONNECTIONS TO THE CENTRAL ELECTRICITY BOARD'S SYS



OMPANY'S SYSTEM

SYSTEM.

PLATE I

There is a single set of main busbars with a section switch at the middle, but on the generator units a second set of busbars is provided through which the generators can be switched on to a load pond for testing purposes.

Circuit-breaker gases are conducted outside the building.

The 11,000 volt local supply switchboard is fed from the main switchboard through current limiting reactors, and from auxiliary generators. It will control the supply to neighbouring localities, and, through 11,000/400 volt station transformers, to the 400 volt auxiliary board. The local supply board is composed of metalclad units, type O.L.D.1A., with a rupturing capacity of 100,000 kVA., and follows the same general principles of construction as the main switchboard, except that castings are employed. Fig. 30 shows the local supply switchboard at Tongland.

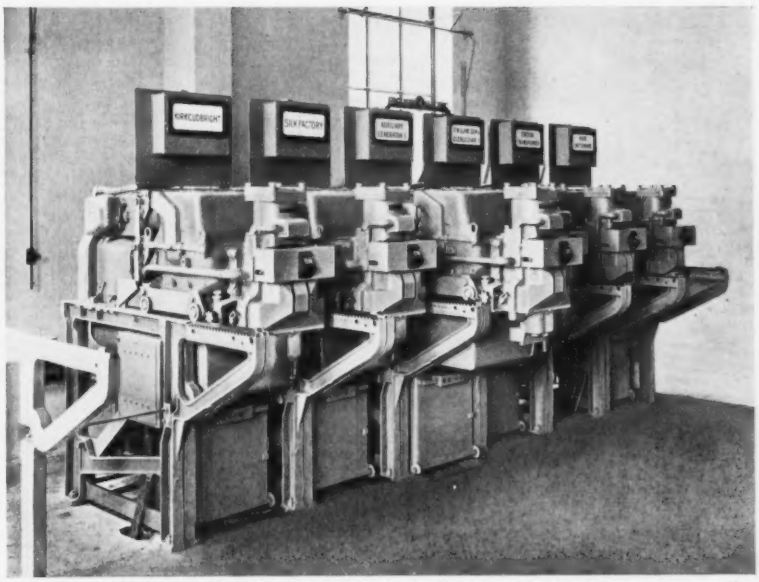


Fig. 30.—11,000 volt, 100,000 kVA. rupturing capacity metalclad Switchgear for auxiliary and local supply at Tongland.

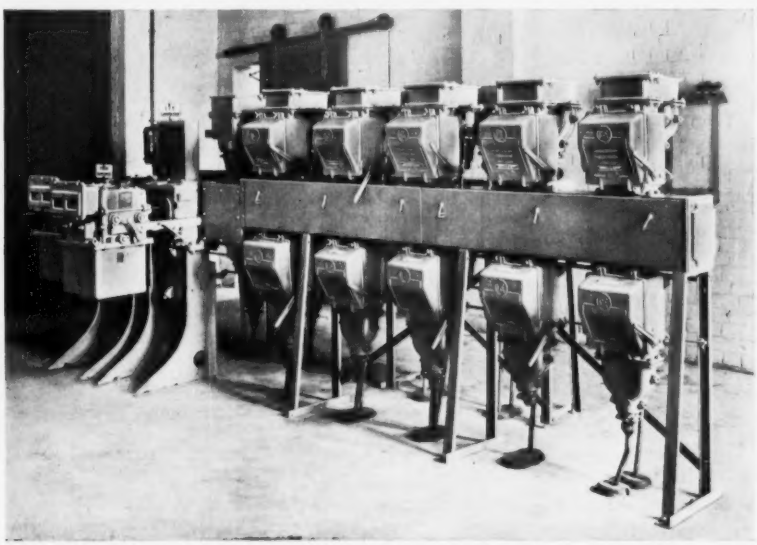


Fig. 31.—The 400 volt and 110 volt auxiliary and Lighting Switchboards at Tongland Power Station.

The 400 volt and 110 volt auxiliary and lighting boards are made up of metalclad type O.L.A.1. switch pillars and "Combination" fuse switches. The "Combination" switches are of the Company's well-known and popular type and comprise an ironclad, airbreak quick-action switch with the fuse cartridge mounted on the blades, which meet the most rigorous safety requirements for this class of apparatus. An illustration of one of these boards is shown in Fig. 31.

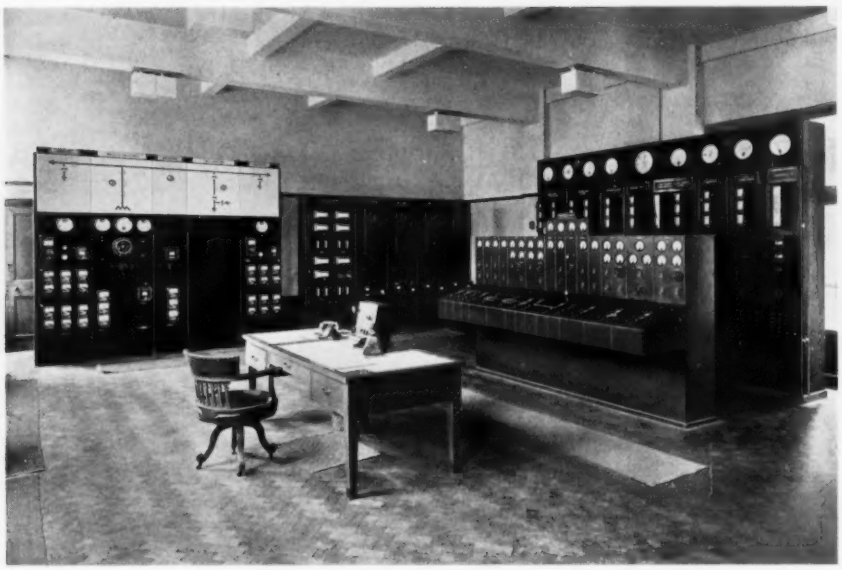


Fig. 32.—The Control Room at Glenlee Power Station.

Duplicate batteries, each 110 volts 500 ampere-hours capacity, operate the circuit-breaker and valve control solenoids, and, in case of failure of the A.C. supply, the automatic emergency lighting.

All control, indication, metering and protective apparatus is located in the control room. The control board for all the 11,000 volt switchgear is of fabricated steel in the form of a desk. Control switches and " mimic " diagrams are carried on the sloping front and indicating instruments are on the upright panels forming the back. All instruments, indicators and switches are of miniature size and are within sight and reach of an operator standing in front of the centre of the board. Automatic indication is given by means of lamp semaphores on the opening and closing of circuit-breakers, and automatic tripping is indicated by the illumination of a white lamp and audibly by a bell. Fig. 32 shows the control room at Glenlee.

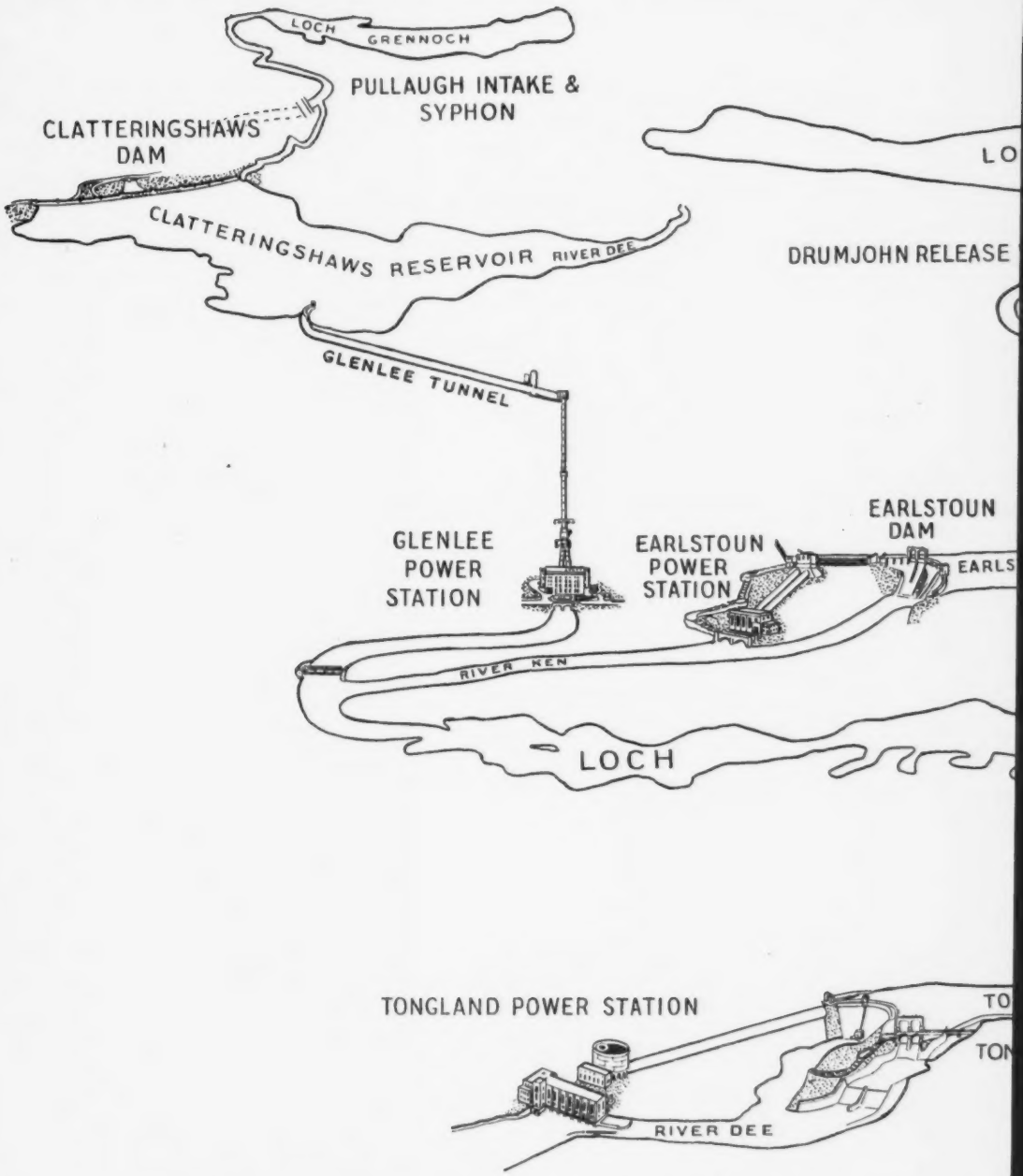
Relays, fuses, integrating meters and automatic voltage regulators are mounted on sheet-steel cubicle-type panels separate from the control desk. The principal types of protection provided are :—

Overload, by means of definite minimum inverse-time relays for all equipments, together with earth leakage (inverse-time) for transformers and Merz - Price circulating current (instantaneous) and over-voltage for main generators.

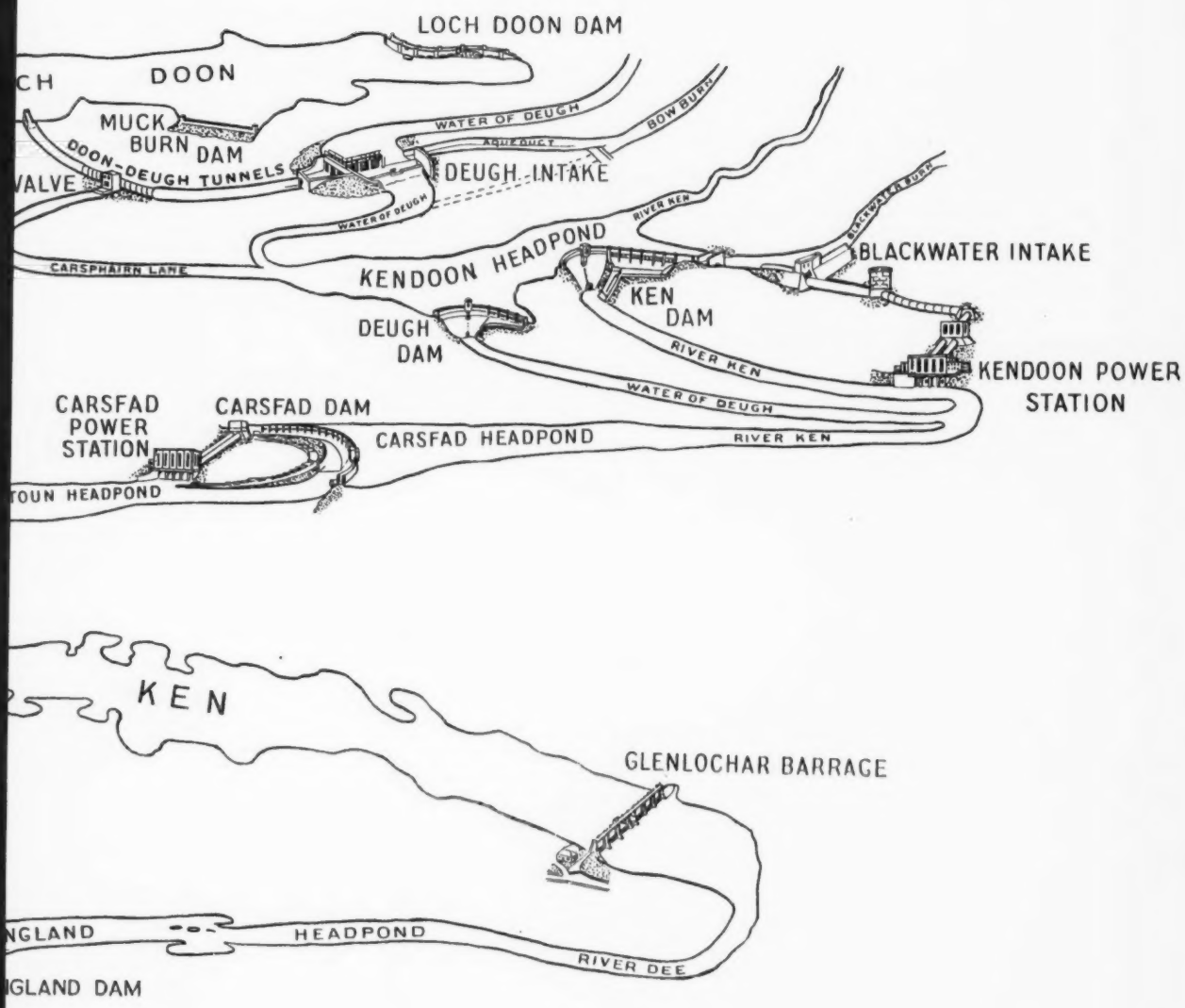
All the apparatus in the control room has been designed and arranged with a view to uniform appearance. All switchboard surfaces, instrument cases and similar apparatus are finished with a special non-reflecting black. No fixing screens or sharp metal edges are visible from the fronts of the boards, which present a most pleasing appearance.

In addition to the equipment described above, switchgear is provided at Glenlee Power Station for the supervisory control of the plant at Earlstoun and Carsfad Power Stations. For this purpose, cubicle type control boards for each of the latter Stations are provided at Glenlee, equipped with control, indicating and selecting apparatus. These boards are of the desk type and are located in the control room at Glenlee.

The photograph of the control room (Fig. 32) was taken before these boards were installed, but the two desks for Earlstoun and Carsfad are



THE GALLOWAY HYDRO-ELECTRIC



SCHEME. A PICTORIAL REPRESENTATION

PLATE II

[*Reproduced by courtesy of*
The Galloway Water Power Company.

[*The English Electric Journal.*

placed conveniently on either side of the operator's seat.

This apparatus, together with the supervisory control equipment generally, will be described at at a later date in connection with the second stage of the Galloway Water Power Company's hydro-electric scheme.

Conclusion.

Glenlee Power Station was put into operation in March, 1935, and Tongland in May of the same year, thus signifying the completion of the first stage of the Galloway Water Power development programme.

The plant at both Stations was put into continuous service with only the very minimum of preliminary trial and adjustment and has run very satisfactorily ever since.

During the six months ended March, 1936, the two Stations together generated 88.5 million units.

This year the Institution of Electrical Engineers held its Annual Summer Meeting in Scotland and made an extensive tour of the Galloway scheme, including the three Stations of the second development, now nearing completion.

By courtesy of The Galloway Water Power Company we are able to reproduce in Plate II a pictorial representation of the Galloway hydro-electric scheme.

Multi-Cylinder Steam Turbines.

By J. T. MOORE, B.Sc., A.R.T.C., A.M.Inst.C.E., A.M.I.Mar.E.

The development of the multi-cylinder turbine has been the result of the general rise in recent years of outputs from individual machines and of initial steam pressures and temperatures, although as early as 1923 the Company was actually constructing multi-cylinder turbines.

These early turbines proved beyond doubt, on the grounds of both reliability and efficiency, that the division of the turbine casing into high-pressure and low-pressure cylinders was a development on the correct lines. It is gratifying to note that at the present day, practically all high pressure and temperature steam turbines for outputs above 12,500 kW. are of the two or three-cylinder design, providing full justification for the past policy of the Company's designers.

The multi-cylinder turbine has the great advantage that all high pressures and temperatures are confined to a comparatively small section of the turbine. The high-pressure cylinder can be made of symmetrical and very simple design resulting in a casting free from residual stresses, and being made of cast steel, there is a complete absence of distortion as the result of high temperature changes. Further, the casing being small, a short robust rotor can be used, and this, with " English Electric " turbines, always is designed with its critical speed well above its running speed. The design of the entire H.P. cylinder is thus well suited to high-temperature working, more especially where considerable temperature changes internally can occur, as in large power stations, with sudden changes in the electrical load.

In some designs of multi-cylinder steam tur-

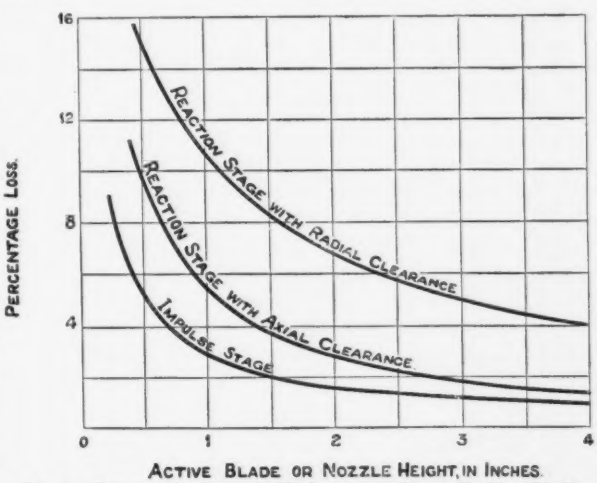


Fig. 1.—Comparative losses in High-pressure Steam Turbine Blading.

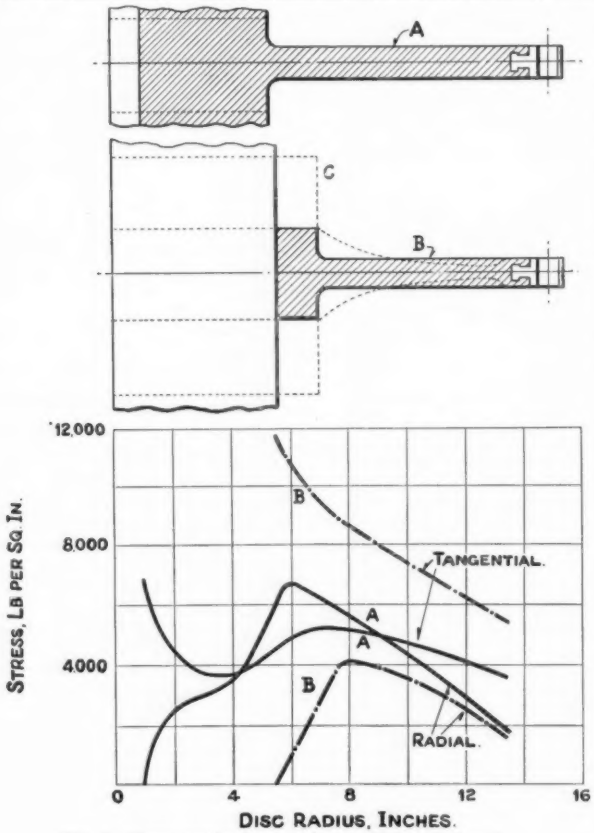


Fig. 2. Comparative stresses in "solid" and shrunk-on discs, for same loading.

bines, the H.P. cylinder is of the pure reaction type or even combined impulse and reaction, but the Company has always avoided the use of reaction blading in H.P. cylinders on account of the small blade clearances which are necessary to obtain reasonably good efficiencies. The higher the initial steam pressure the smaller will be the blade heights at the H.P. end, and it therefore follows that the blade tip clearance with unshrouded blades must be very small to keep down the leakage over the blade tips. Alternatively, if the blades in high-pressure reaction turbines are shrouded to permit of safe blade tip clearances, the axial clearances must be kept very fine. Fig. 1 illustrates the above point, and is taken from the paper by A. H. Law and J. P. Chittenden read before the Institution of Electrical Engineers in 1927.

With reaction blading there is a pressure drop across each rotating and stationary stage, and this necessitates fine clearances, which is a natural drawback of reaction blading for the higher ranges of steam pressure. This necessity for fine clearances has been the reason for the development of end-tightening in reaction turbines, but contrary to the practice with impulse blading, it is necessary to adjust the axial clearances for different loads, if the efficiency is to be maintained.

If set for minimum axial clearance at light load the clearances at loads approaching the maximum would be too great, due to the expansion of the rotor, for good efficiencies to be obtained, while if set for minimum clearances at normal or maximum load, fouling would result at light load.

With impulse blading, on the other hand, there is no pressure drop across the rotating blades in each stage ; pressure drop occurs only in the stationary diaphragms. This eliminates the necessity for very fine blade clearances as in reaction turbines, and enables H.P. cylinders with impulse blading to be designed to give ample clearance under all load conditions. The clearances, both axial and radial, can be set for a particular load and no further adjustments are required during service running. The slight variations in clearances at different loads as the result of temperature changes, have no effect on the efficiency of impulse blading.

The H.P. rotor of " English Electric " multi-cylinder turbines is notable for the fact that the discs are forged integral with the shaft thus permitting the use of normal carbon steel for the discs as well as the shaft. The discs, being solid with the shaft, are capable of withstanding much higher centrifugal loading without the stresses exceeding the safe limits. For the same conditions of loading the lower stresses in discs integral with the shaft in comparison with the stresses in separate discs shrunk on to the shaft, is shown very clearly by the curves in Fig. 2.

This illustration also is taken from the paper by A. H. Law and J. P. Chittenden referred to previously.

When large disc diameters come into question, alloy steels are necessary to withstand the resultant centrifugal stresses. Such separate discs, when not subject to high temperatures, have given every satisfaction in service but in all "English Electric" high-speed multi-cylinder turbines, they are used only when the steam temperature in the turbine has reached a comparatively low figure. In some of the designs of the Company's two-cylinder turbines, the last few stages in the H.P. cylinder are fitted with separate discs of alloy steel when these are not subjected to high temperatures, but in high-speed machines discs integral with the shaft are used without exception for the inlet end and the major portion of the H.P. cylinder. It may be argued that alloy steels are perfectly capable of withstanding high temperatures, but the policy of the Company is to use separate discs of this type only where the steam temperatures are sufficiently low to leave no possibility of removing the effect of the original heat treatment of the discs, or by causing the discs to expand unduly, thus making them loose on the shaft at speed.

The foregoing considerations have formed for many years the basis of the design of the H.P. cylinder of "English Electric" multi-cylinder turbines, these being always of the pure impulse type with the attendant advantages of having no very fine blade clearances, no adjustments being necessary to the clearances during running, no cylinder distortion as the result of a complicated design of casing, no vibration troubles due to the rotor having to run through a critical speed when starting up or shutting down, and having uniform heating and cooling of the rotor on account of its shortness and simple form.

The low-pressure cylinder of the Company's multi-cylinder turbines has various forms, each designed to meet special sets of conditions, but in all cases the blading is of the reaction type. The advantage of the use of reaction blading lies in the fact that larger steam volumes are dealt with in the L.P. cylinder. As a result, the blades are long and the blade clearances can all be sufficiently large to ensure complete reliability while at the same time the efficiency is not affected to any appreciable extent by such large clearances. This follows from the fact that the amount of the clearance, although ample for service running, is only a very small percentage of the blade height. A further and extremely important advantage of using reaction blading in the L.P. cylinders of large turbines is the resultant elimination of the large diaphragms which are necessary with impulse designs. On account of the large volumes of steam to be handled, such diaphragms, across each of which there is the full pressure drop of each stage, must of necessity be of massive construction to withstand the effects of the considerable bending moments set up by the difference in pressure on each side. There is thus a great bulk of metal in such L.P. diaphragms and with sudden temperature changes in the turbine, always the tendency to distort with the consequent possibility of fouling the following disc or moving blades or, perhaps even more serious in many cases, severe touching of the diaphragm shaft glands. Touching of the shaft glands may not do more in many cases than increase the gland clearances, with a lowering of the efficiency, but a continuous touching may very soon cause undue heating and eventually shaft distortion.

As manufacturers of impulse turbines of the single-cylinder type for medium and small outputs, the Company has an unrivalled experience, extending over many years, in the use of diaphragms in impulse turbines, and their experience has proved that very large diaphragms must always be a potential source of trouble for the aforementioned reasons. Their elimination by the use of reaction blading in large L.P. cylinders does not, however, involve a sacrifice of efficiency, as prolonged tests by the Company, as well as by independent authorities, have shown that, neglecting the effect of blade clearances, the hydraulic efficiency of reaction blading is superior to that of impulse blading. Thus, with large steam volumes as in the L.P. cylinders of multi-cylinder turbines, where the blade clearances are of relatively minor importance, the overall efficiency with reaction blading can be maintained at a high figure without impairing the reliability.

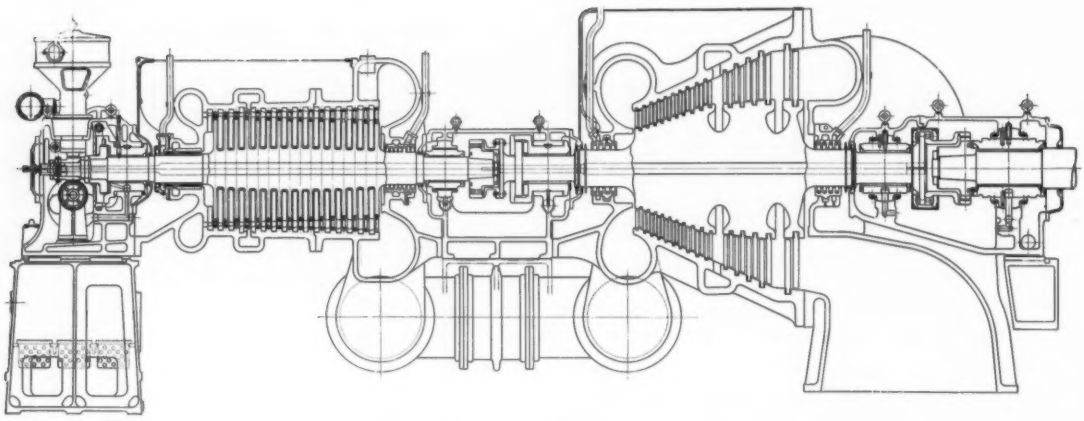


Fig. 3.—Sectional arrangement of Two-Cylinder Impulse-Reaction Steam Turbine for medium outputs Single-flow Low-pressure Cylinder.

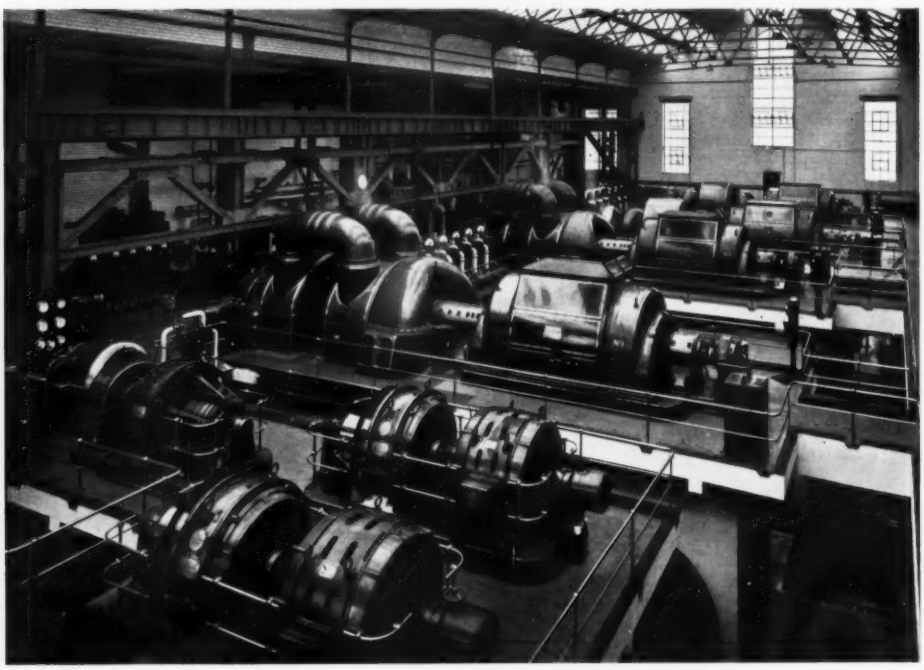


Fig. 4.—Four 15,000 kW. Two-Cylinder Turbo-Alternator Sets in the Preston Corporation Power Station.

Moreover, with impulse blading in large low-pressure turbines, the shaft diameters at the diaphragm glands must be kept as small as possible to keep down leakage losses through the glands. This, with the long span shafts necessary in such turbines, prohibits the use in most cases of large diameter shafts with the first critical speed well above the running speed. As a rule, therefore, and more especially where high efficiency is required, the rotors of large L.P. turbines with impulse blading are required to run through the first critical speed on starting up or shutting down.

In view of the above considerations, the policy of the Company has been to avoid the use of impulse blading in the L.P. cylinders of their multi-cylinder turbines and to use only reaction blading. On the grounds of both efficiency and reliability in service, this policy has been more than justified by the results obtained with the large number of their multi-cylinder machines already installed in this country and abroad.

For small outputs and up to about 20,000 kW. at 3,000 r.p.m. with a vacuum of about 29 in., the L.P. cylinder is generally of the single-flow, single-exhaust type on the lines of the unit shown in Fig. 3.

Units of this type have been supplied for the Ribble Power Station of the Preston Corporation (two 15,000 kW. sets, shown in foreground of Fig. 4), the Aberdeen Corporation (12,500 kW.), the Dalmarnock Power Station of Glasgow Corporation (27,500 kW. at 1,500 r.p.m.), the Cawnpore Electric Supply Corporation, India (12,500 kW. and 15,000 kW. machines) and many others. For high vacuum and outputs in the region of 25,000 kW. at 3,000 r.p.m. or if twin-condensers are specially desired at smaller outputs, the L.P. cylinder is of the outwards double-flow twin exhaust design shown in Fig. 5. The L.P. rotor is also of the solid type with its first critical speed well above the running speed. Many two-cylinder turbines of this type are in service and two machines of this design can be seen in the background of the illustration in Fig. 4. Similar units have also been installed at the Central Power Station of Leicester Corporation (25,000 kW. illustrated in Fig. 6), the Banhida Power Station, Budapest (three 23,000 kW. machines), City of Athens (three 15,000 kW. machines), Peterborough Corporation (12,500 kW.), and other stations.

For larger outputs, the L.P. rotor is built up of individual discs mounted on a shaft, and for 3,000 r.p.m. machines the rotor is of the double-flow type. For outputs in the region of 30,000 kW. to 50,000 kW. at 3,000 r.p.m., the two halves of the L.P. rotor are separate and the flow is towards a central exhaust as shown in Fig. 7. This design has proved highly successful in service and 30,000 kW. turbines of this type, similar to that

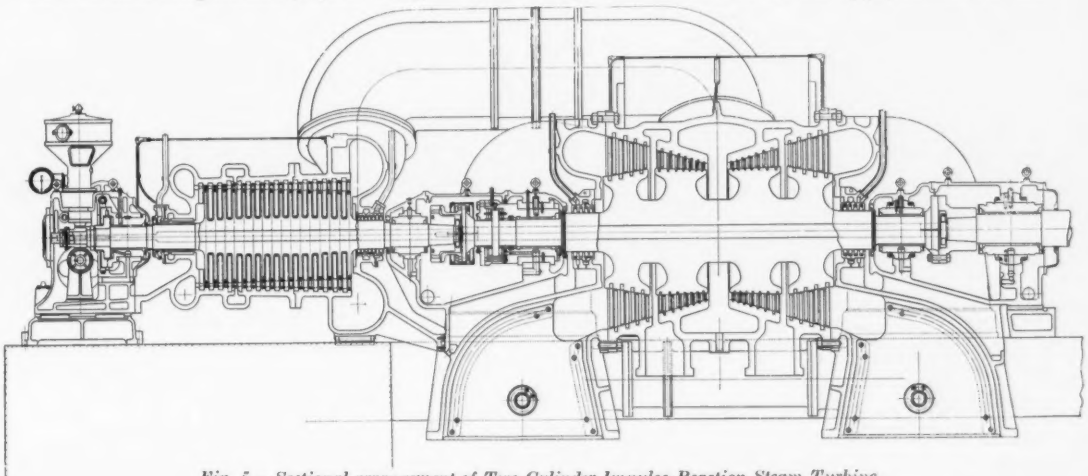


Fig. 5.—Sectional arrangement of Two-Cylinder Impulse-Reaction Steam Turbine. Double-flow Low-pressure Cylinder with twin Exhaust Outlets.

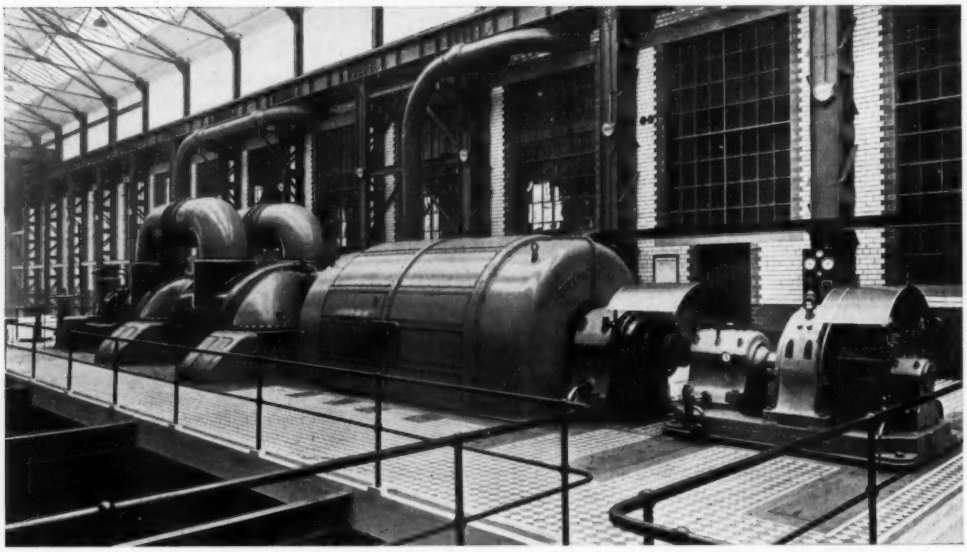


Fig. 6.—25,000 kW. Two-Cylinder Turbo-Alternator Set at Leicester Corporation Power Station.

shown in Fig. 8, have been running for some years at the power stations of West Ham and Bradford Corporations, and the Thornhill Power Station of the Yorkshire Electric Power Co. In passing, it may be mentioned that the 30,000 kW. set at West Ham has generated over five consecutive years an average of 75 per cent. of the total units generated in the Station, and at Thornhill the 30,000 kW. set there has generated over three years an average of 95 per cent. of the total units generated in the station. A second 30,000 kW. turbo-alternator set of the same design is at present being completed for the Thornhill Power Station of the Yorkshire Electric Power Co. and a photograph of this unit in the course of erection in the Shops is shown in Fig. 9. Two 30,000 kW. turbo-alternator sets with turbines of the same design are also in course of manufacture for the Stourport Power Station of the Shropshire, Worcestershire and Staffordshire Electric Power Co. Ltd.

Alternatively for large outputs up to about 50,000 kW. at 3,000 r.p.m., the L.P. cylinder would be generally of the design shown in Fig. 10, i.e., an outwards double-flow arranged with a single-exhaust, but which, if necessary, could readily be converted to a twin-exhaust arrangement. This design embodies on one shaft the two half L.P. rotors separate in the design shown in Fig. 7, but each half having somewhat fewer stages in order to obtain a comparatively short span between bearings. The H.P. rotor on the other hand, has more stages to compensate for the smaller number in the L.P. cylinder, but in other respects the design embodies all the features which have proved so successful in the 30,000 kW. turbines at West Ham, Bradford, and Thornhill.

For still higher outputs at high vacua the speed would be 1,500 r.p.m. but the design would remain generally similar to that shown in Fig. 10 with a single or twin-exhaust arrangement.

A further type of multi-cylinder turbine evolved by the Company is the three-cylinder design in which both the H.P. and I.P. cylinders are of the pure impulse type while the L.P. cylinder is of the reaction type arranged with an outwards double-flow rotor and twin-exhaust. The illustration in Fig. 11 shows the design of the 25,000 kW. and 30,000 kW. turbines of this type which have been installed at the Blackburn Meadows Power Station of Sheffield Corporation and for which Station a third 30,000 kW. unit is at present in course of manufacture.

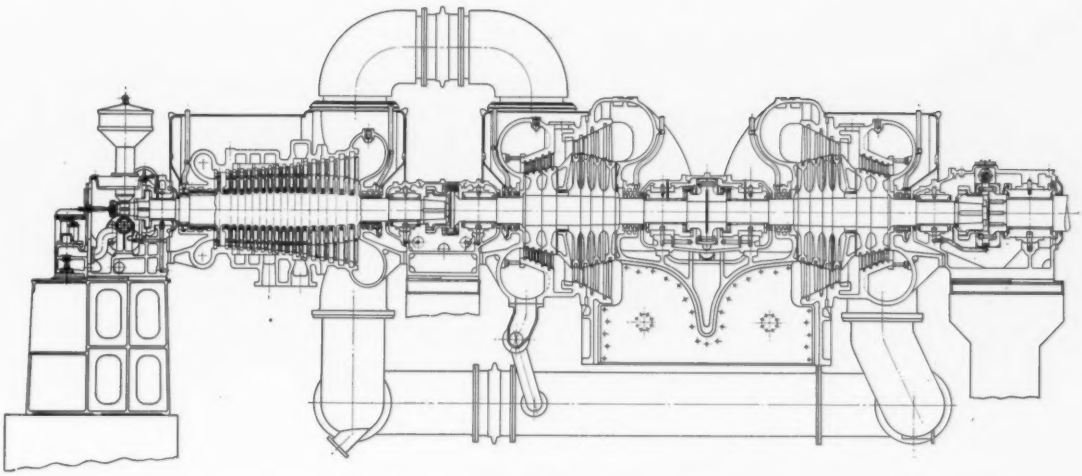


Fig. 7.—Sectional arrangement of a Two-Cylinder Impulse-Reaction Steam Turbine for large outputs at 3,000 r.p.m. Inwards Double-flow Low-pressure Cylinder.

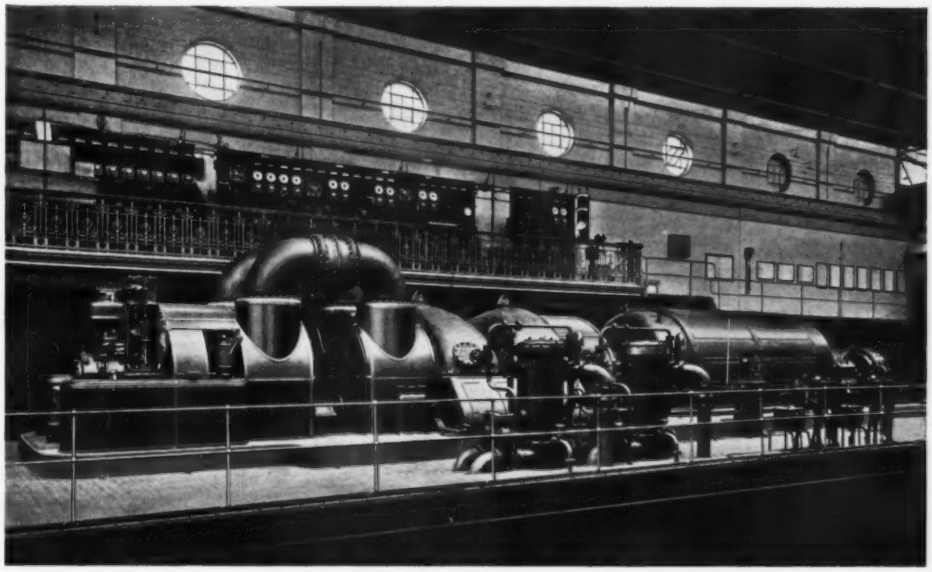


Fig. 8.—30,000 kW., 3,000 r.p.m. Two-Cylinder Turbo-Alternator Set at West Ham Power Station.

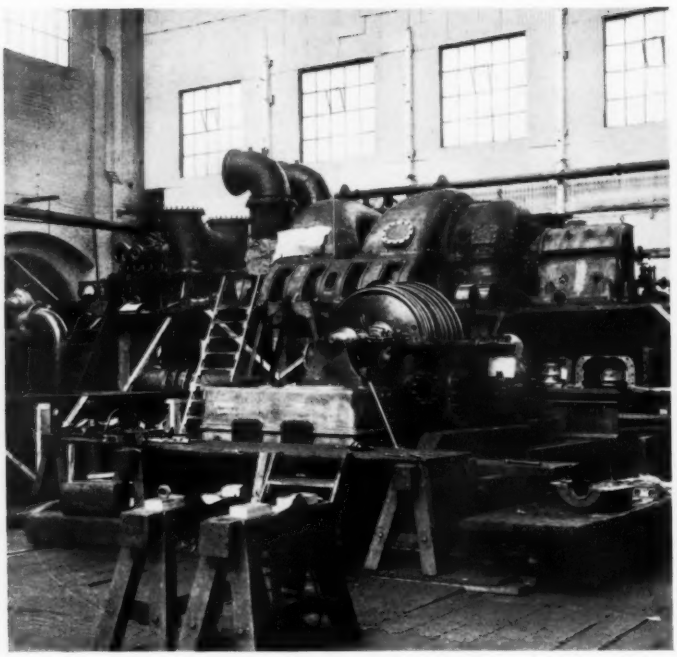


Fig. 9.—30,000 kW. Turbine in course of erection at the Company's Rugby Works.

As an example of the reliability of the Company's design of multi-cylinder turbine, it may be mentioned here that the above 25,000 kW. set at Sheffield, generated during last year a total of 189,000,000 units, and was in operation for 92.7 per cent. of the total possible running hours in the year. This performance corresponds to an average load of 21,600 kW. over the above period and when it is remembered that the maximum output of the set is only 25,000 kW. it constitutes a remarkably good record.

For very high steam pressures and temperatures, the three-cylinder design has the advantage that the rotors are very short, more especially that in the H.P. cylinder, the three cylinder casings can readily be made of the most suitable material

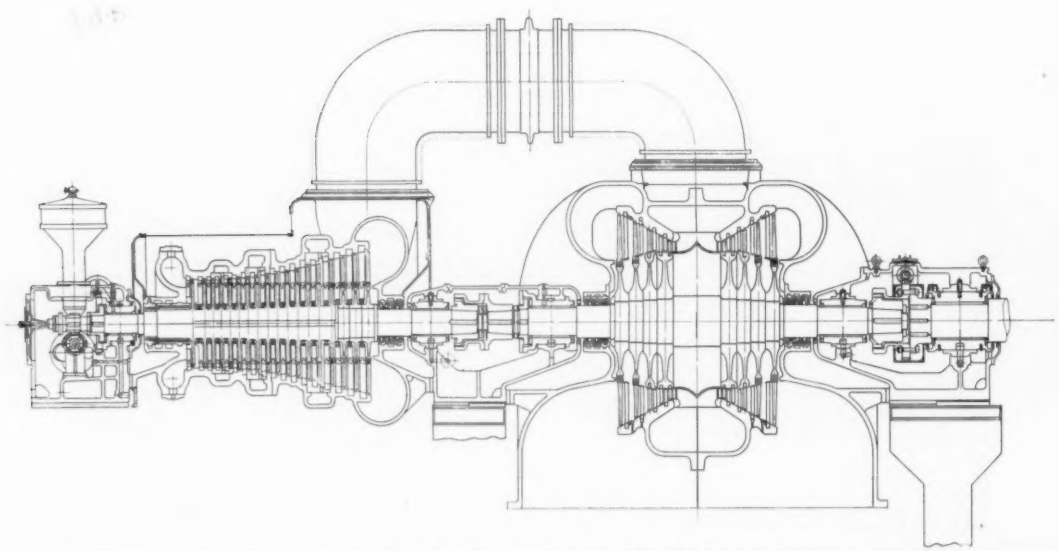


Fig. 10.—Sectional arrangement of Two-Cylinder Impulse-Reaction Steam Turbine for large outputs at 3,000 r.p.m. Outwards Double-flow Low-pressure Cylinder.

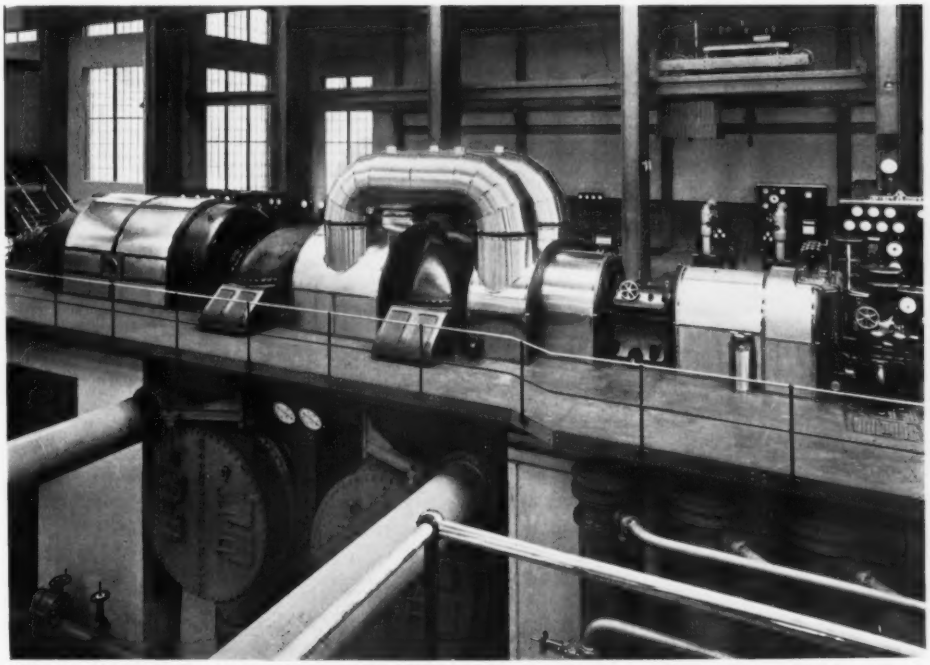


Fig. 11.—25,000 kW., 3,000 r.p.m. Three-Cylinder Turbo-Alternator Set at the Blackburn Meadows Power Station of Sheffield Corporation.

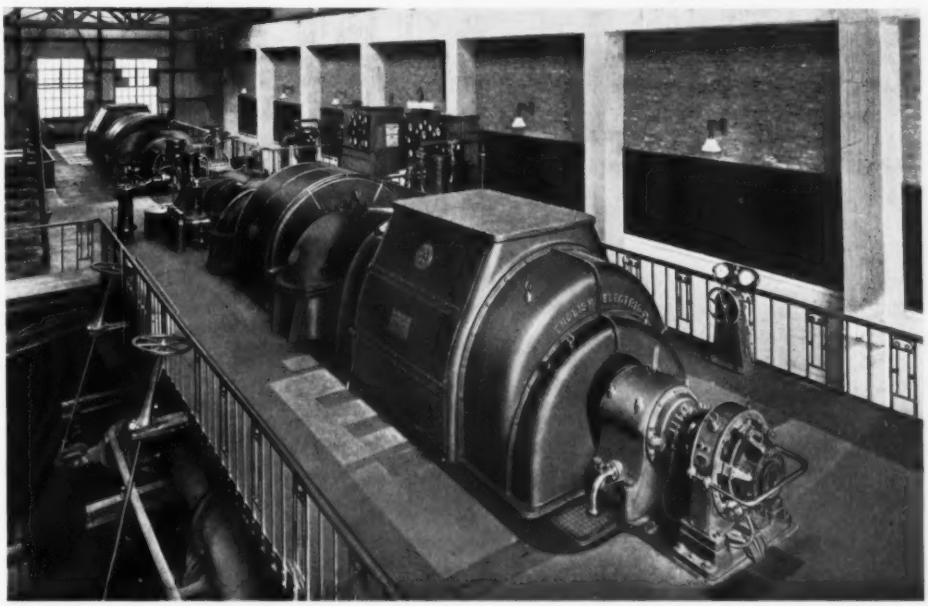


Fig. 12.—Two 12,500 kW. Two-Cylinder Turbo-Alternator Sets at the Kemsley Mills of Messrs. Edward Lloyd Ltd.

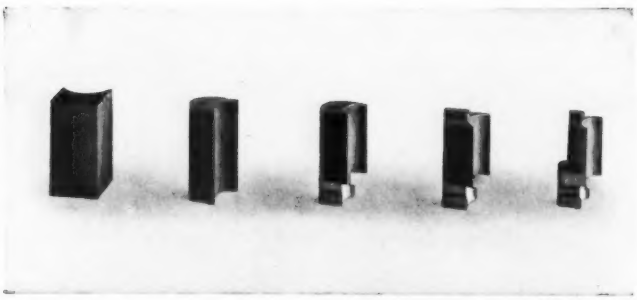


Fig. 13.—Construction of Steam Turbine Impulse Blading.

for the temperatures occurring. For example, with a very high initial steam pressure and temperature, the casing of the H.P. cylinder subjected to the highest temperatures could be made of molybdenum cast steel, that of the I.P. cylinder subjected to more average temperatures, of normal cast steel, and that of the L.P. cylinder where all temperatures are comparatively low, of close-grained cast iron. Thus, by a suitable choice of materials and with the very short, stiff rotors, distortion and vibration as the result of sudden temperature changes, can be eliminated.

Industrial power stations do not generally use machines of large output, but even so, the company has supplied a considerable number of multi-cylinder turbines for this class of work. In 1926 and 1928, two 12,500 kW. two-cylinder turbo alternator sets were installed at the Kemsley Mills of Messrs. Edward Lloyd Ltd., Sittingbourne, and these machines have given excellent service since their installation. One machine has actually been in service now for 6 years without "opening up" during that period, and, moreover, has generated more or less continuously throughout the 6 years, being shut down on the average only on alternate Sundays. The units generated by this machine during the above period make the impressive figure of 387,500,000 units, the corresponding average load being of the order of 8,000 kW.

In addition to these two 12,500 kW. turbines, there is also installed in the same power house a 15,000 kW. two-cylinder pass-out turbo-alternator set which at the time of ordering was one of the largest pass-out turbines to be installed in this country. The general design of all three of these multi-cylinder turbines at Kemsley Mills follows the Company's standard practice with an impulse H.P. cylinder and a reaction double-flow L.P. cylinder. The illustration in Fig. 12 shows the two original 12,500 kW. sets.

As an instance of the high quality of manufacture in the Company's multi-cylinder turbines, the rotating blading is milled entirely from the solid bar with roots integral with the main blades. The type of blade fixation employed for the impulse blading in the H.P. cylinder is shown in Fig. 13, and the normal type for L.P. reaction blading in Fig. 14.

By machining the blades with roots from the solid it is possible to ensure that the correct design angles are obtained, while, at the same time, the solid root ensures that the blade is rigidly held in its correct position even under conditions of great temperature change.

The diaphragms in the H.P. cylinder of "English Electric" multi-cylinder turbines, are

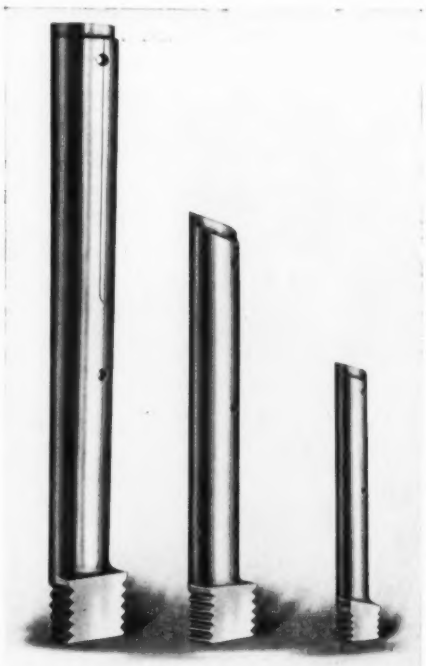


Fig. 14.—Low-pressure Reaction Blading.

of the built-up type, enabling the nozzles to be very accurately made and assembled with a steel centre piece after the manner shown in Fig. 15. This construction gives an exceedingly strong diaphragm but of simple and symmetrical form not liable to distortion, more especially as the centre piece can be of material most suitable for the maximum steam temperatures occurring in the turbine.

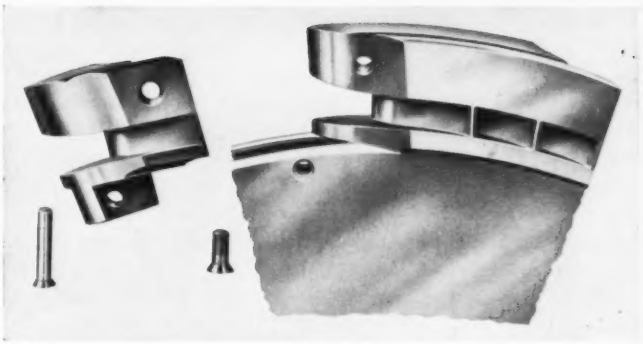


Fig. 15.—Details of "Built-up" Nozzle Construction.

Resulting from the modern use of high steam pressures and from the high efficiencies now obtained with large multi-cylinder turbines, the steam in the final stages of the L.P. cylinder contains a large percentage of moisture. Much research work has been carried out by the Company with a view to reducing the erosive effect of this moisture on the L.P. blading, and highly successful results have been obtained both in extracting as much as possible of the water from the steam as it passes through the L.P. blading and in preventing serious erosion of the rotating blading in the last few L.P. stages. Fig. 16 shows two of the methods employed for trapping the water before the following rotating row and leading the water thus trapped direct to the condenser. As it is impossible to trap and extract all the water in the steam at any stage, means have to be employed to protect the moving blades in the final stages and the method of doing this is illustrated by the longest blade shown in Fig. 14, and the diagram in Fig. 16. The shielding on the inlet side of the blade is of special steel which, after being brazed on the blade as shown in the illustrations, has the property of air hardening to a Brinell hardness of approximately

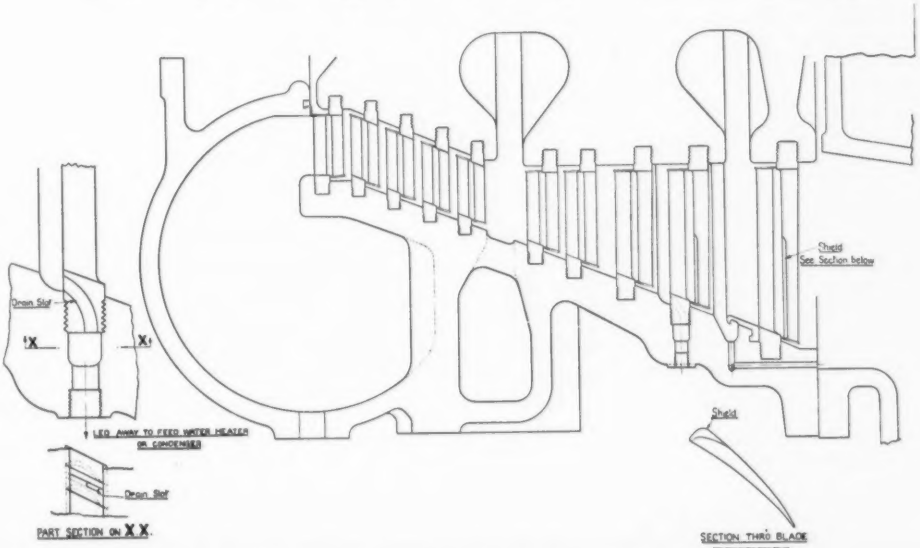


Fig. 16.—Sectional Diagram illustrating method of trapping water in final low-pressure stages.

600, thus giving a highly resistant surface at the points where the water strikes the blade and erosion is most severe on an unshielded blade. This method of shielding L.P. blading has been used by the Company for many years with excellent results, and is now standard practice for the last few L.P. stages in all multi-cylinder turbines. As an example of the results obtained, a 12,500 kW. two-cylinder turbine installed in this country nine years ago, showed after five years' operation, erosion of the inlet edges of the last three L.P. moving rows to the extent of about $\frac{1}{16}$ in. to $\frac{3}{32}$ in. wear. The inlet edges of the blading in these last three rows were then fitted with shielding and when opened up for inspection recently, the shielding was in practically as perfect a condition as when originally fitted. At the present rate of erosion on the shielding, the life of these three rows of blading should be not less than the life of the turbine as a whole.

In conclusion, it cannot be too strongly emphasised that reliability is all-important in power station practice, and it is on this ground that "English Electric" multi-cylinder turbines have proved their worth in service. It is not a difficult matter to obtain high efficiency alone on any carefully designed turbine, but high efficiency, coupled with steady reliability, is obtainable only when potential sources of trouble have been entirely eradicated. This is justly claimed for the Company's multi-cylinder turbine, with its special combination of impulse and reaction blading.

Scientific Developments in Transformer Construction.

By R. M. CHARLEY, M.C., B.Sc., M.I.E.E., Mem.A.I.E.E.

In "The English Electric Journal" published during 1928 and 1929 were several articles which described the evolution of transformer construction and indicated probable developments in the near future, and in the issue of January, 1930, was a description of some of the first 132 kV. transformers supplied to the Central Electricity Board for the National Grid. It may be of interest to give some notes of ways in which practice has changed and progressed during the past few years and to describe some typical examples of modern transformers. It is proposed, in the first section of this article, to refer to special problems of design and their solution, and then to describe some transformers supplied for the Grid and systems associated with it, together with some further interesting examples of large transformers, and finally, to mention some new special applications of transformers.

Transformers on the Grid.

The first transformers on the Grid were put into service in 1929 on the Central Scotland Scheme. Since that time the Grid has been continually expanding until now practically the whole country is covered by primary or secondary transmission lines, and about 7,400 mV.A. of 132 kV. and about 2,900 mV.A. of 66 kV., or lower voltage transformers have been installed. In practically every instance on-load tap-changing equipment was provided.

In the early days it was the policy of the Central Electricity Board to specify 30 mV.A. as the largest three-phase unit, above which capacity banks of single-phase units were to be used, although, even at that time some manufacturers offered to build three-phase units of even 100 mV.A. It was not long, however, before transformers of the maximum output required for the Grid were supplied as three-phase units, and many 60 mV.A. and 75 mV.A. units have been installed. Banks of single-phase units were supplied only on the Central Scotland Scheme, which was the first section of the Grid. Recently, it has been considered that 45 mV.A. is the most suitable maximum size of unit. The most modern example of a transformer of this output for 132

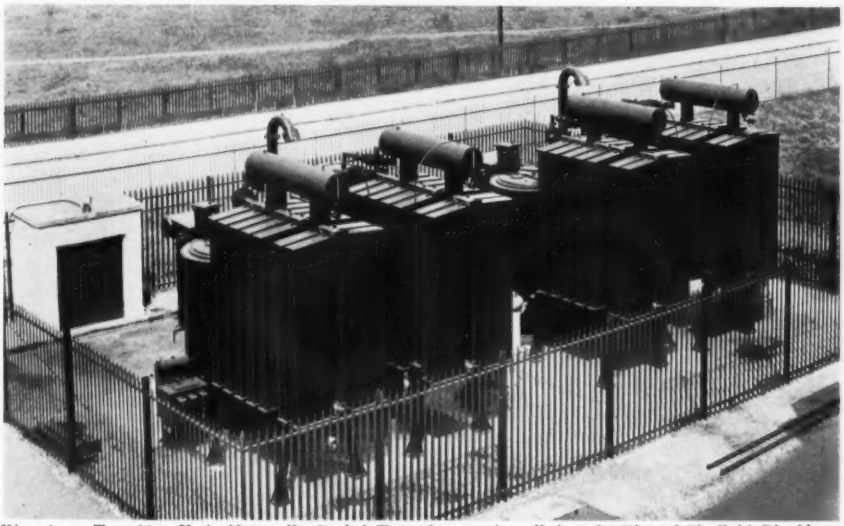


Fig. 1. — Two 20 mV.A. Naturally-Cooled Transformers installed at the City of Sheffield Blackburn Meadows Power Station.

kV. service will be described in a later section of this article. The units are for the Grid sub-station at the new Fulham power station, where they step-up the Fulham bus-bar pressure from 66 kV. to 132 kV. for connection to the Grid.

Large Naturally Cooled Transformers.

Originally 10 mV.A. was looked upon as the largest naturally cooled transformer, above which capacity air-blast cooling was used with or without the addition of forced-oil circulation. To-day, a number of 20 mV.A. naturally cooled units are in service, and 40 mV.A. units with natural cooling only, are being built. For 20 mV.A. units the naturally cooled type costs about seven per cent. more than the forced-oil air-blast cooled type, and for 40 mV.A. units the difference is about twelve per cent. Although these figures indicate an appreciable extra initial cost for natural cooling, it must be remembered that a large part of the difference is reduced by the saving of capitalised cost of power for running the auxiliaries, and of supervision and maintenance. Another important factor is that the output of the artificially cooled transformer, at least the output above half-load which it may be capable of supplying without any auxiliary equipment running, is dependent on comparatively small motors and their ancillary gear. In many cases the sub-station is normally unattended. Taking all factors into account, the author urges that the extra cost for natural cooling, even for the larger transformers, is fully justified in most cases. Fig. 1 illustrates two 20 mV.A. naturally cooled transformers.

The above argument attempts to justify natural cooling as against air-blast cooling, but if water cooling is under consideration, the extra cost for natural cooling is much greater. In certain cases, as for example, where site accommodation is limited, or for transformers installed at power stations, this method of cooling may be economically sound. For 20 mV.A. the difference in cost is about twenty per cent., and for 40 mV.A. it is about thirty per cent., but as explained above this difference is partly offset by the cost of auxiliary equipment. A typical example of a large transformer with forced-oil circulation and water cooling will be illustrated in a later section of this article.

The figures given in the last two paragraphs refer more particularly to 33 kV. or 66 kV. transformers; for 132 kV. units the percentage difference in cost would be somewhat higher.

Mechanical and Thermal Problems of Design.

In the design of large modern transformers it must be emphasized that the problem has serious mechanical and thermal features in addition to electrical considerations, in fact, it might be said that, in the larger units, the mechanical problem assumes almost greater importance than any other. At the same time, it should be remembered that the mechanical, thermal and electrical characteristics are interdependent to a very large extent. The following examples illustrate how these features must be co-ordinated in order to produce the best design.

Cooling Arrangement for Large Cores.

It is essential to provide cooling ducts in a large core, but this must be done without detriment to the solidity of the core, otherwise there would be harmful effects causing increased vibration, and consequently noise, and further, the reliability of the core might be prejudiced. Since the co-efficient of heat transference along the plane of the laminations is about twenty times as good as it is across the laminations, it is obviously preferable to locate cooling ducts in a core at right angles to the plates. Fig. 2 illustrates a large three-phase core in which this is done. The slots in the laminations are so placed that the complete duct passes across the core in a series of steps. Fig. 3 shows the arrangement of the slots in detail. The illustrations show how the limbs are clamped with a single row of bolts, which construction is used up to the largest sizes. This design of core gives the most efficient cooling of the laminations, with the greatest possible space factor and mechanical robustness.

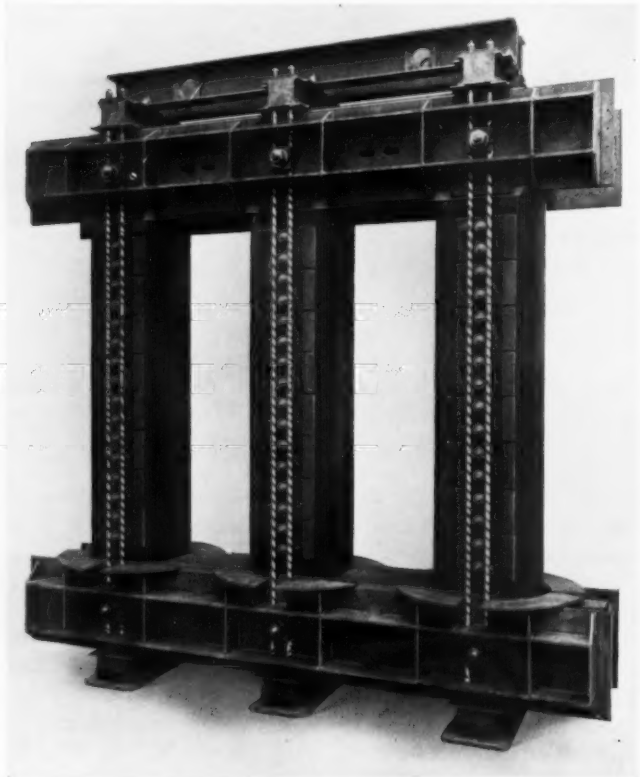


Fig. 2.—Typical core as used for large Transformers.

Cooling of Windings in Relation to Mechanical Strength.

There must be ample provision for cooling the windings, but in making this provision it must be ensured that the bracing of the windings is adequate to withstand the mechanical forces produced under short-circuit conditions. This feature applies not only to the windings as a whole, but to other individual features, such as the spacers between disc coils where the length of unsupported conductor must not be so great that it would bend under the mechanical force. Also the dimensions of the conductor itself must be chosen with due regard to the bending stress.

Windings must Withstand Mechanical Forces Produced under Conditions of External Short-circuit.

Perhaps the greatest difficulty in the design of a large transformer is to ensure that it will withstand the mechanical forces produced by a short-circuit on the secondary terminals with full voltage maintained on the primary side. With the

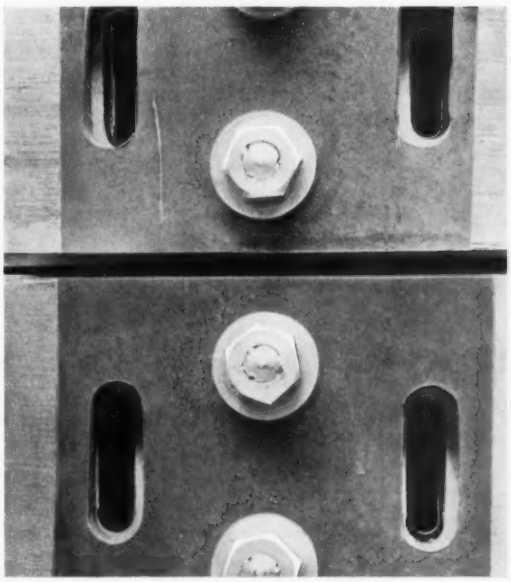


Fig. 3.—Cooling ducts for large cores.

present large size of power stations and the vast interlinking between stations and systems, it is rarely safe to rely on any external reactance ; in other words, the short-circuit current through a transformer is limited only by the reactance of the transformer itself. Thus a transformer having 10 per cent. reactance will allow ten times full load current to pass through it. Moreover, the mechanical force is proportional to the square of the current.

The difficulty of this problem is greatly accentuated by the inclusion of tappings in the winding, particularly if they cover a wide range. It is now common practice to equip large transformers with on-load tap-changing gear, and 20 per cent. range is very commonly demanded, but sometimes, for special reasons concerning voltage regulation, perhaps due to interchange of power in both directions, the voltage range must be 25 per cent. or even 30 per cent. Although this presents a big difficulty, it can be overcome by judicious arrangement of the windings with particular relation to the tappings. The ideal arrangement would be to maintain symmetry between the H.V. and L.V. windings under all tapping connections. This is only partially possible, but much can be done to improve conditions. It has been the practice for many years to place the tappings in the centre of the column ; one improvement is effected if the tappings are separated into two groups at the centre of the top and bottom halves of the column. Conditions could be made almost perfect if the arrangement of turns in the L.V. winding could be changed for

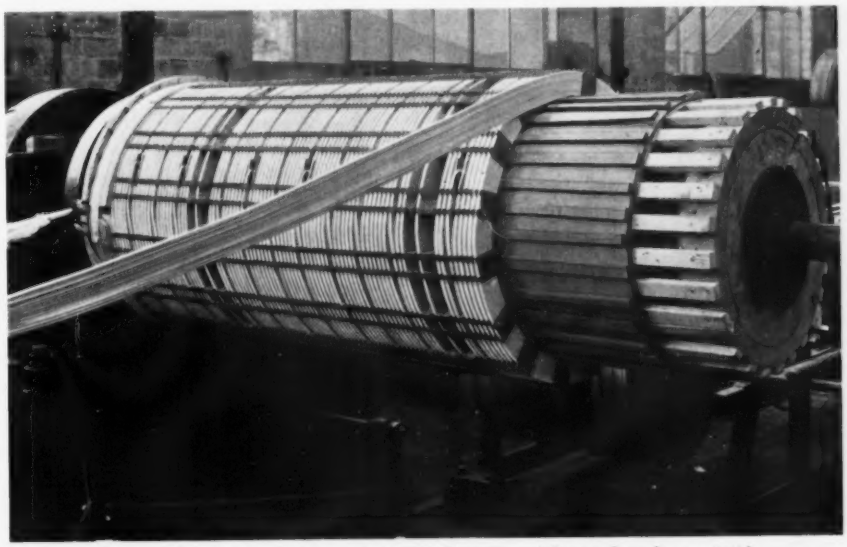


Fig. 4.—Special low voltage winding with gaps. (*For explanation see text.*)

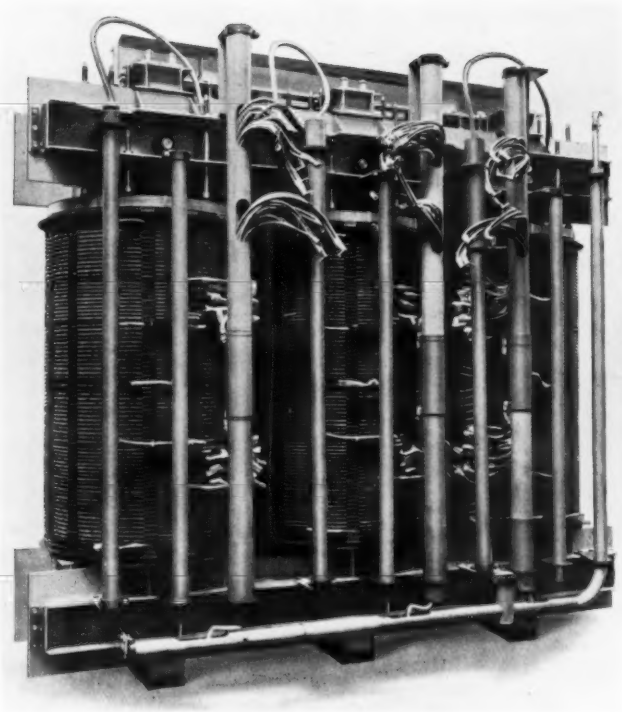


Fig. 5.—24 mV.A., 66 kV. Transformer winding with complicated connections for various service conditions.

each tapping connection in the H.V. winding. Obviously, this is a practical impossibility, but the special "English Electric" scheme* goes a long way in that direction. Opposite each group of H.V. tapping coils there is a gap in the L.V. winding; in practice the height of this gap is made about half the height occupied by the H.V. tapping coils. This scheme reduces the mechanical force to about 60 per cent. of the value it would have if there were two groups of H.V. tappings, without the special L.V. winding, and to about 29 per cent. of the force that would exist with the old arrangement of one group of H.V. tappings without the special L.V. winding. Fig. 4 shows a single-layer spiral coil in which the feature described above is incorporated.

* *This scheme is described in more detail in an article by A. T. Chadwick published in the October, 1934, issue of "The English Electric Journal."*

Large Transformer with Complicated Connections and Wide Range of Voltage Tappings.

A striking example of a transformer in which the problem discussed in the last three paragraphs assumed great difficulty is illustrated in Fig. 5. The design was complicated by the fact that it was necessary for the transformer to be suitable for two different voltage ratios each with a different vector relationship, and in both cases an exceptionally wide range of on-load tap-changing was required. The initial service of the transformer was at 40 cycles and later at 50 cycles, with an output of 12 mV.A. at a normal voltage ratio of 20/11.5 kV., the windings being star-delta connected, and the on-load tap changing equipment on the H.V. or primary side being arranged to allow for a primary voltage variation from 17.6 kV. to 24.2 kV., a total range of 37 per cent. in 19 steps. For its final and permanent service, the transformer is capable of an output at 50 cycles of 24 mV.A., at a voltage ratio of 66/20 kV., the windings being star/star connected, with a tertiary winding, and the same on-load tap-changing equipment being re-connected on the H.V. or primary side to give a voltage range on the L.V. or secondary side from 18.9 kV. to 25.3 kV., this being a range of 34 per cent. in 19 steps. For both connections all parts of the windings are in use, but, obviously, a very large number of leads are necessary to enable the reconnection to be made. Fig. 6 shows the above transformer completely assembled. It is of the forced-oil air-blast cooled type.

Variation of Impedance and Eddy Current Loss.

The special arrangement of windings described above is of value not only in relation to mechanical forces, but in limiting the variation of the impedance values over a wide range of tappings to a reasonably low degree. In a large trans-

former that will be described later in this article, the impedance varied only 6 per cent. throughout the tapping range of 24 per cent.

The same feature has a beneficial effect in minimising the eddy current loss in the windings, which with the old arrangement of windings might increase to a serious extent with more and more of the tapping winding being cut out of the circuit. This effect is most serious in that it would cause local heating which must be prevented, otherwise, in course of time the winding would be damaged.

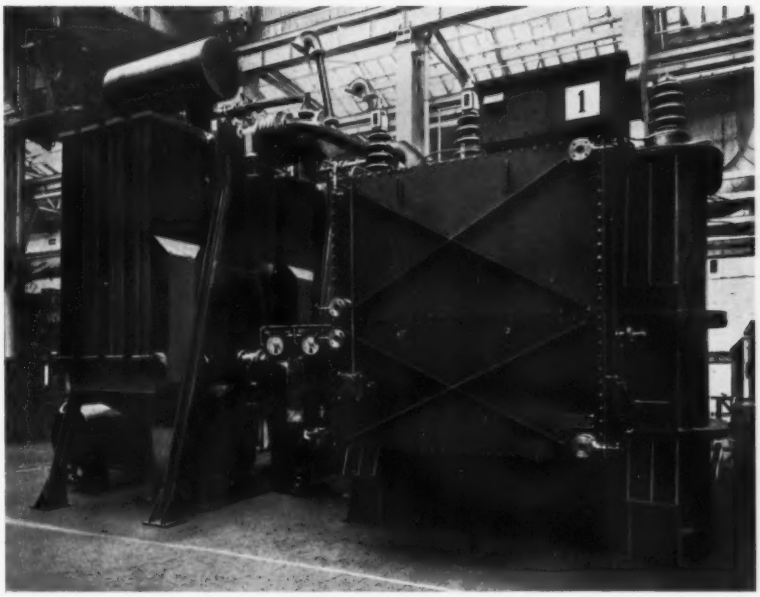


Fig. 6.—24 mVA., 66 kV. Transformer installed on the North Eastern Electric Supply Company's system.

Transient Surge Voltages.

During the past few years much data has been collected, by research in laboratory and in the field, also by theoretical investigation, in regard to the effect of transient surge voltages on transformer windings. Co-ordination of the insulation of the line and transformer is an important consideration. The surge strength of the transformer must be determined with adequate knowledge of the characteristics of the line, and bushings must be chosen so that their impulse strength is lower than the transformer winding. Designed with the knowledge now available, transformers are much less susceptible to transient surge conditions than they were in the past, although obviously it cannot be guaranteed that they will withstand all conditions that may arise.

Noise and its Reduction.

The question of noise emanating from transformers has exercised the minds of operators and designers very much recently. It must be recognised that a large transformer cannot be built to operate with complete silence, but much can be done to minimise the amount of noise produced. The first criterion is that of flux density in the core: balancing the benefit gained against the increased cost the value should be reasonably low, say, about 12,000 lines per square centimetre. But in addition to this feature, great care must be taken in the design of the core, and the clamping of it; the multi-step construction shown in Fig. 1 contributes to the reduction of noise. Then the tank construction must be carefully designed so that vibration of the plates in harmony with the core vibration is reduced to a minimum. Great care must be taken to ensure that the many small items on a transformer are suitably designed and are well fitted, otherwise a very small detail may cause a very disconcerting noise.

Under some circumstances, further expenditure may be justified in order to reduce the noise to an even lower level. Fig. 7 illustrates a 20 mV.A. transformer in which the Company's patented noise-reducing design has been employed. In the design of the core and windings and tank all the precautions mentioned in the last paragraph were taken. Around the outside

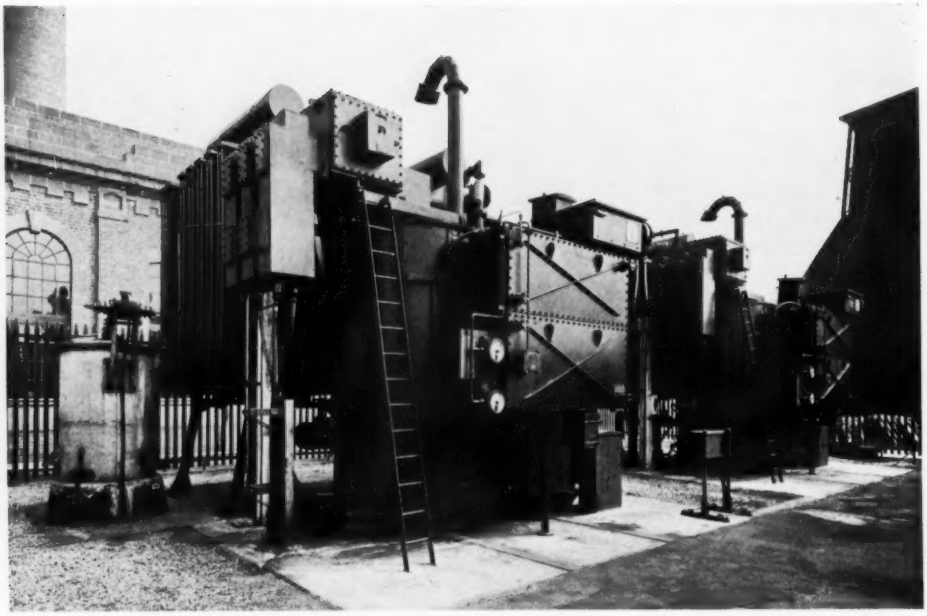


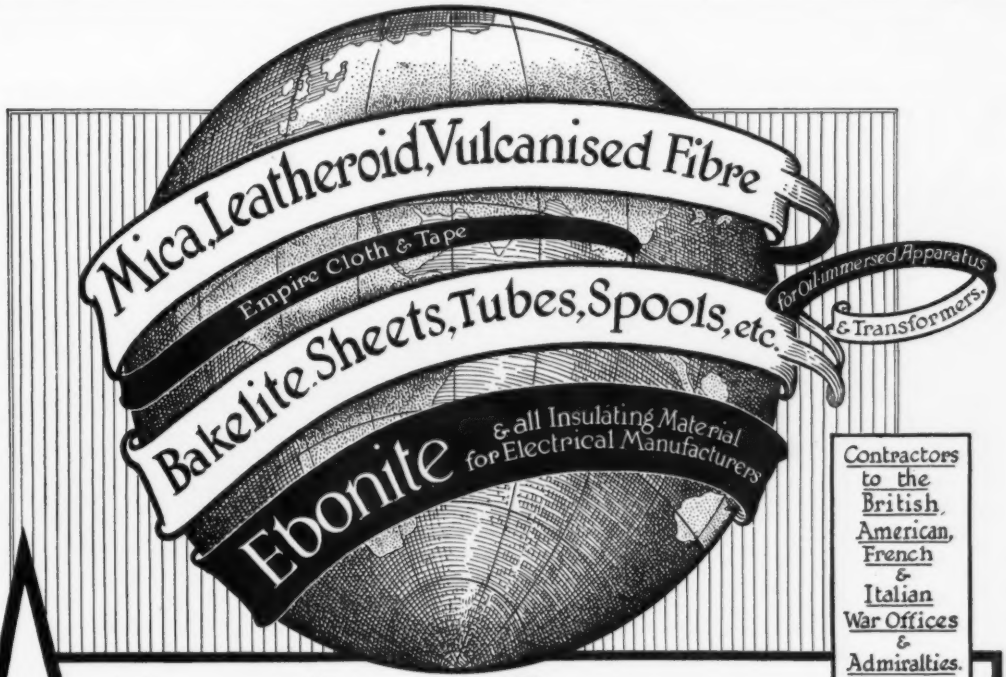
Fig. 7.—20 mV.A., 33kV. Naturally Cooled Transformers installed at the Bury Substation of the Central Electricity Board.

of the tank is a steel shell fixed in such a way that there is no metallic contact between it and the tank ; at the bottom it rests on pads of rubber and at points where pipe connections pass through the shell, rubber washers are inserted. The annular space between the tank and outer shell is six inches and contains still air which is a good sound insulator. Two of these transformers have replaced two units of 10 mV.A. capacity which were also designed with low flux density in the core. Careful measurements of noise were made under similar conditions with the old and new transformers, and it was found that the noise from the new 20 mV.A. transformers was only about half that from the old 10 mV.A. units.

The 20 mV.A. transformers shown in Fig. 7 are naturally cooled and they are accommodated on the same foundations as the original 10 mV.A. units.

An interesting feature of these transformers is the provision of an isolating switch on the H.V. side. It is located in a separate oil-filled chamber between the cable boxes and the main tank and is arranged to isolate the transformer from the cables and earth the transformer.

(*This article will be continued in the next issue.*)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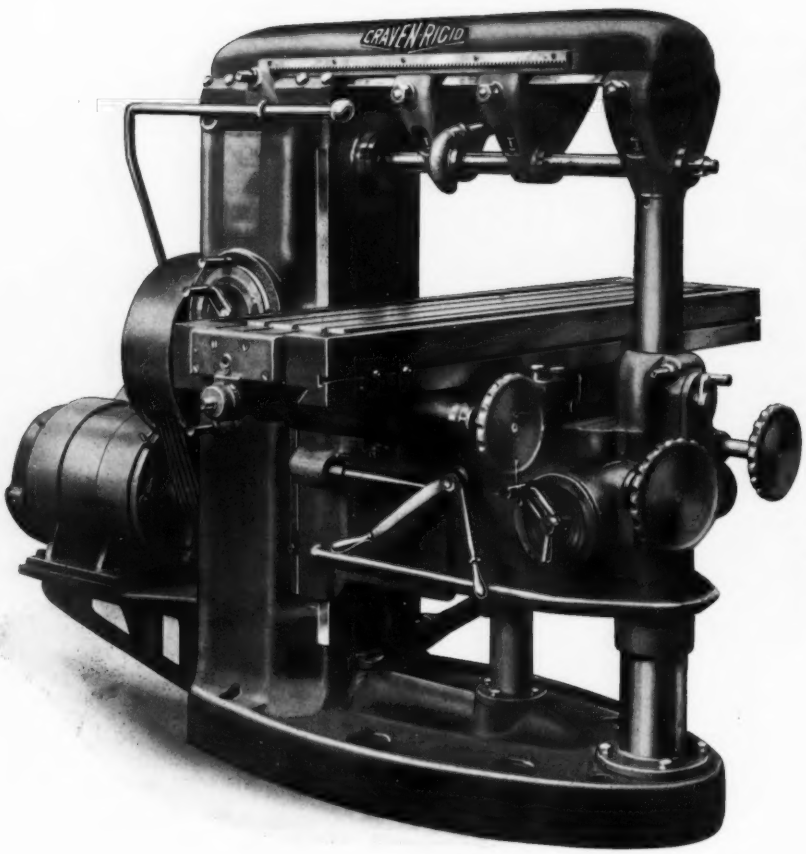

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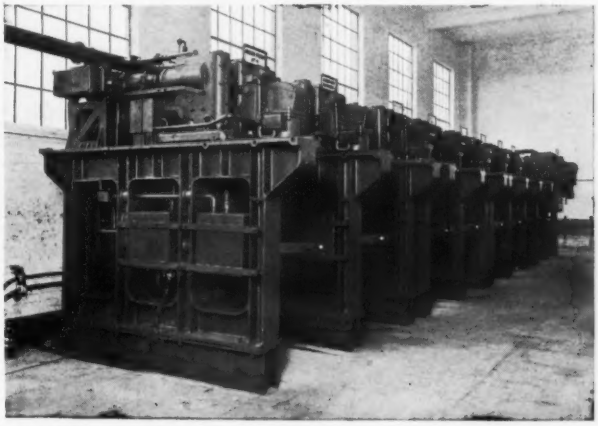

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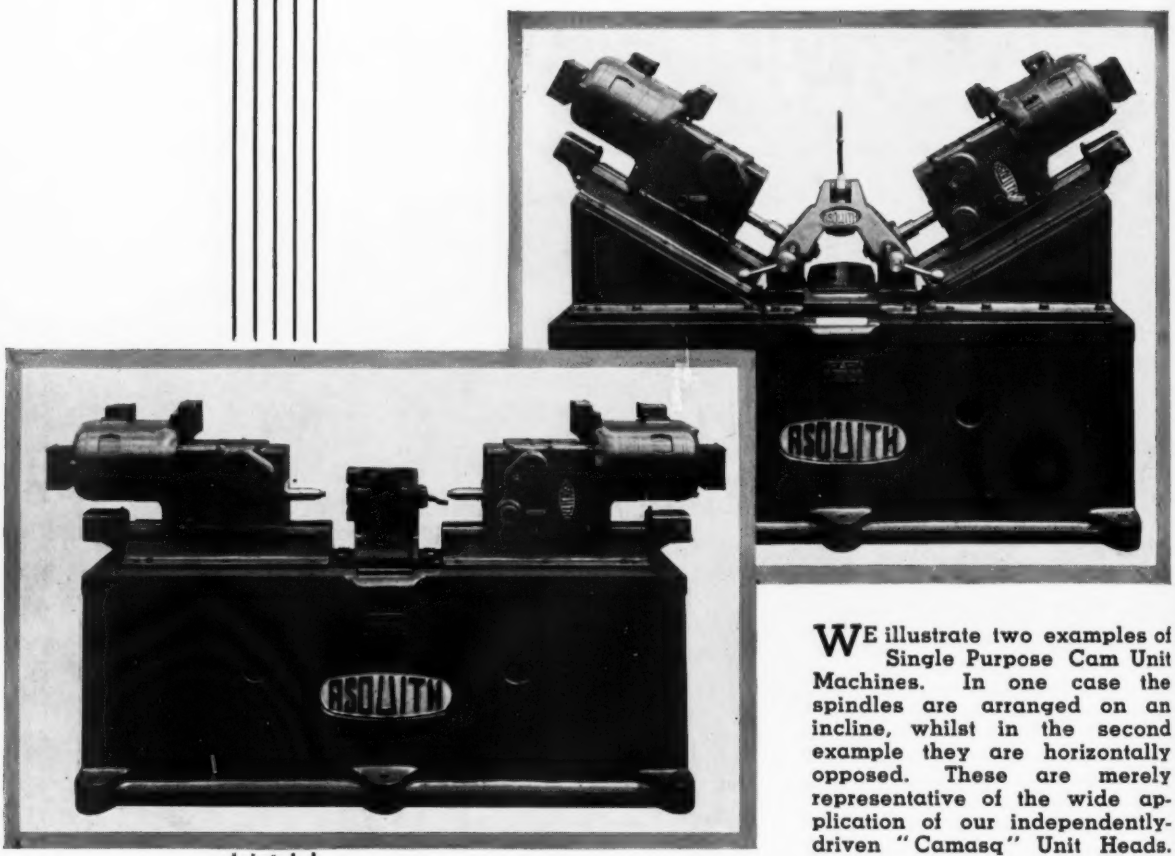

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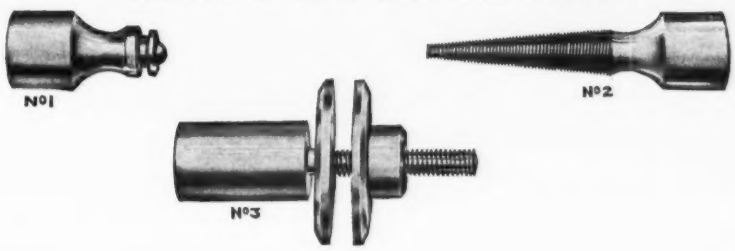

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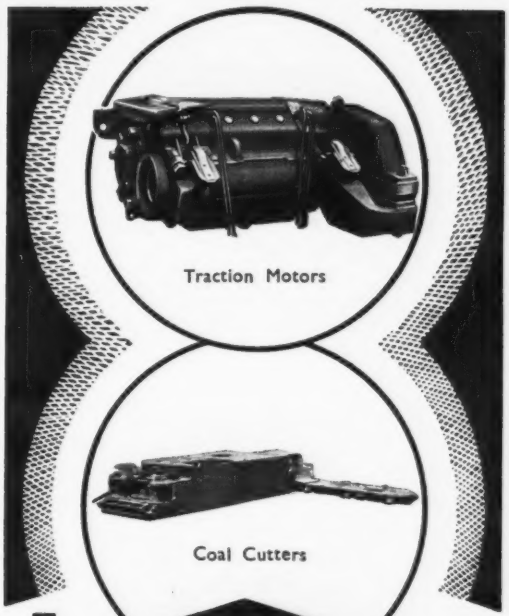

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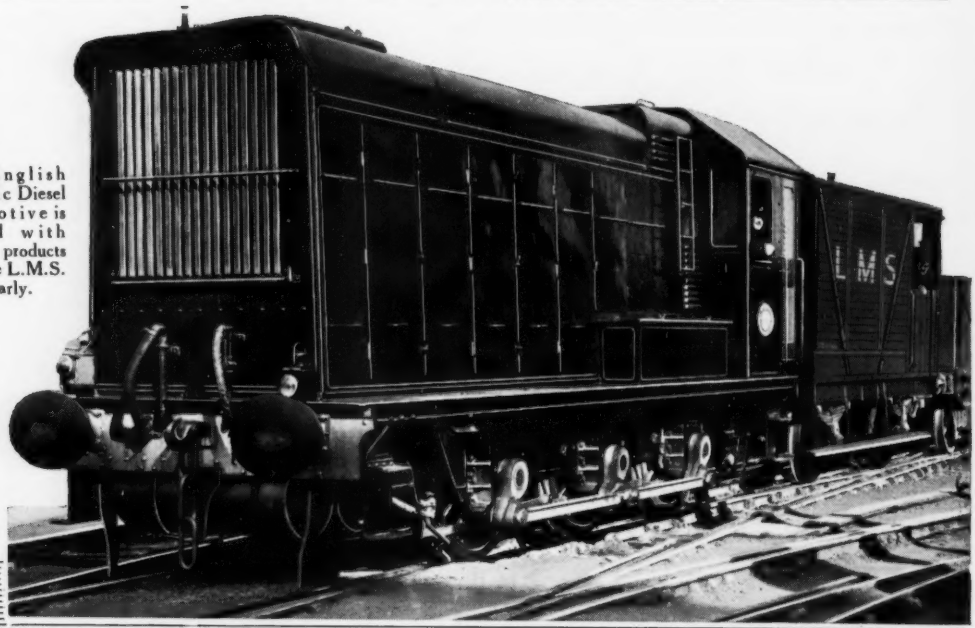

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